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Journal

of the

American Welding Society

April, 1929

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by the

AMERICAN WELDING SOCIETY

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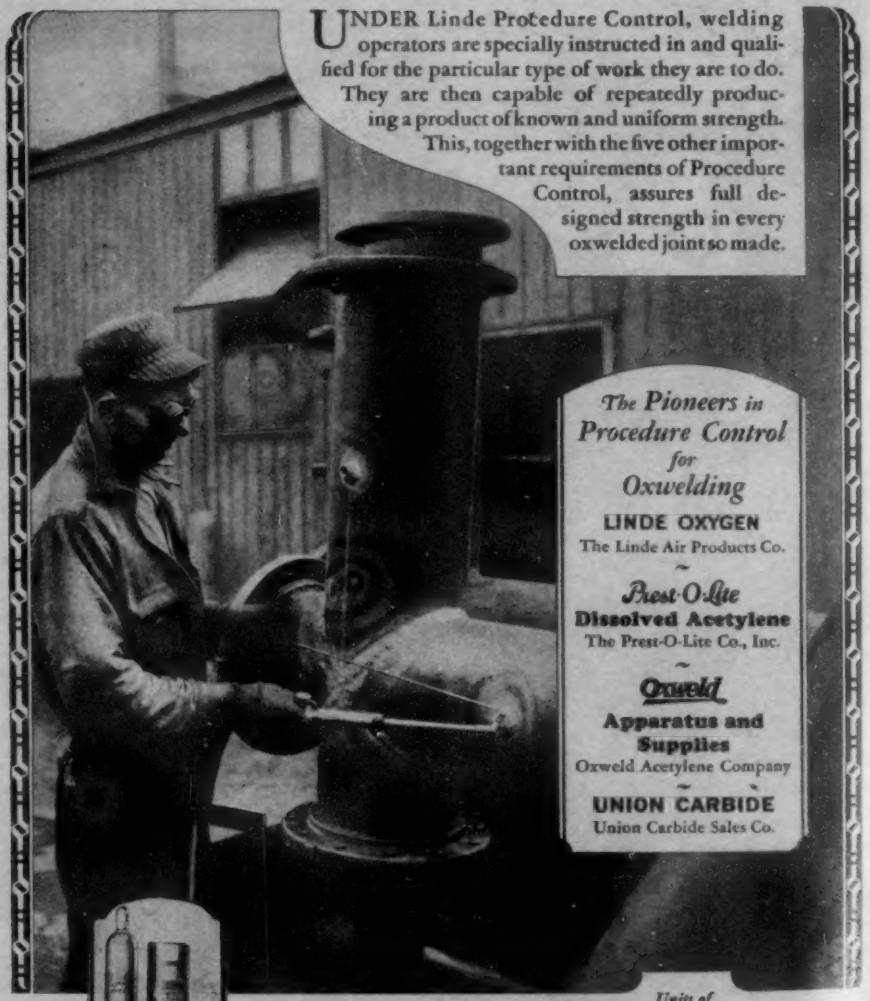

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JOURNAL

of the

AMERICAN WELDING SOCIETY

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AMERICAN WELDING SOCIETY
ESTABLISHED 1919
JOURNAL

Volume 8 APRIL, 1929 Number 4

PROGRAM

ANNUAL MEETING

AMERICAN WELDING SOCIETY

33 West 39th Street

April 24, 25 and 26, 1929

All Sessions Start Promptly as Scheduled

IMPORTANT NOTICE

Members and their guests are requested to register

WEDNESDAY, APRIL 24, 1929

Morning

Technical and Business Sessions

10:00 a. m. to 10:30 a. m., Room 2, 5th Floor, Business Meeting, F. T. Llewellyn, President, Presiding.

Report of President, Report of Tellers' Committee, Election of Officers, Presentation of Miller Medal.

10:30 a. m. to 12 noon, Room 2, 5th Floor, Technical Session, C. A. McCune, Presiding.

A symposium on "How to Organize and Operate an Industrial Welding School."

C. E. Conway, Educational Director, Bedford Branch, Young Men's Christian Association.

R. K. Randall, Cleveland Welding School.

L. S. Thurston, General Electric Company.

F. E. Sellman, Consulting Engineer, Servel, Inc.

F. E. Rogers, Publicity Manager, Air Reduction Sales Company.

N. E. Wagner, Prairie Pipe Line Co.

R. R. Lincoln, Manufacturing Engineer, Westinghouse Electric & Manufacturing Company.

J. C. Lincoln, Lincoln Electric Company.

M. R. Bass, Asst. Director, The William Hood Dunwoody Industrial Institute.

WEDNESDAY, APRIL 24 (*Continued*)

Afternoon

Technical Session

2:00 p. m. to 5:00 p. m., Room 2, 5th Floor, Technical Session, F. M. Farmer, Presiding.

"Strength of Butt Welds," by G. Lobo, Westinghouse Electric & Manufacturing Company.

"High Pressure Distribution of Manufactured Gas by the Aid of Welded Pipe Lines," by C. M. Hendry, E. L. Phillips & Company.

Evening

Board of Directors' Meeting

6:00 p. m., Dinner Meeting, Engineers' Club, 32 West 40th Street, New York.

Meeting of Board of Directors of American Welding Society will be preceded by a subscription dinner. Appointment of committee chairmen and other officers. Committee reports. Plans for the coming year.

THURSDAY, APRIL 25, 1929

Morning

Technical Session

10:00 a. m. to 12, Room 2, 5th Floor, F. T. Llewellyn, President, Presiding.

"Design of Joints for Welded Steel Structures," by A. Vogel, General Electric Company.

"Welding in the Heating and Ventilating Industries," by Prof. S. E. Dibble, Carnegie Institute of Technology.

Luncheon

A luncheon for members of the Society will be arranged at the Engineers' Club. Tickets at $2.00 each may be obtained from the Secretary.

Afternoon

Technical Session

2:00 p. m. to 5, Room 2, 5th Floor, A. G. Oehler, Presiding.

"Welding in the Aircraft Industry," by R. M. Mock, Bellanca Aircraft Corporation.

"Thermit Welding of Rail Joints for Main Line Track of Steam Railroads," by J. H. Deppeler, Metal & Thermit Corporation.

THURSDAY, APRIL 25 (*Continued*)

Evening

Annual Dinner

6:30 p. m., Hotel Pennsylvania, 7th Avenue at 32nd Street.

The dinner, as last year, will be arranged as a stag affair. Extraordinary entertainment has been provided by the Dinner Committee. There will be no speeches. Tickets should be secured from the Secretary at once. Price $6.00 per person.

FRIDAY, APRIL 26, 1929

Morning

Technical Session

10.00 a. m. to 12, Room 2, 5th Floor, E. A. Doyle, Presiding.

A symposium on "Welding in the Chemical and Process Industries."

"Welding Aluminum in the Chemical Industry," by W. M. Dunlap, Aluminum Company of America.

"The Production of Ductile Welds in Nickel and Monel Metal," by N. B. Pilling, International Nickel Company.

"Welding of Pressure Vessels for High Temperature and Pressures," by T. McLean Jasper, A. O. Smith Corporation.

"Welding in the Chemical and Process Industries," by A. G. Wikoff, Carbide & Chemical Corporation.

"Welding Duriron," by P. D. Schenck, The Duriron Company, Inc.

Afternoon

Annual Meeting

American Bureau of Welding

2:00 p. m. to 3:45, Room 3, 5th Floor, C. A. Adams, Director.

Review of Progress made by various research committees of the Bureau. Plans for future investigational activities. Election of officers. Appointment of Executive Committee.

3:45 to 5:30 p. m., Room 3, 5th Floor.

Meetings of Structural Steel Welding Committee, J. H. Edwards, Chairman.

Review of progress made to date. Discussion of future activities of committee.

Discussion of Technical Papers Particularly Invited!

Instruction Manuals

A number of copies of the Instruction Manuals for arc, resistance and thermit welding are still available. These may be purchased at 50c. per copy, with special price in quantity lots of twenty-five or more.

These manuals give a résumé of information in their respective fields and are designed particularly for the student welders and engineers.

Obituary

Harold J. Horn

Harold J. Horn, Sustaining and Charter Member of the American Welding Society, died on Wednesday, Jan. 30, at his home in Pennington, N. J., from pneumonia. Mr. Horn was 52 years old and connected with the John A. Roebling's Sons Company for the past thirty years.

He graduated in 1898 from Lehigh College as valedictorian of the engineering school. Upon graduating he entered the employ of the John A. Roebling's Sons Company and recently was appointed assistant manager of production. His great knowledge of the product, experience in manufacture and familiarity with every process particularly qualified him for this work. He possessed an unusual knowledge of the properties of materials and was widely known as a wire expert.

Mr. Horn was a member of the following engineering and technical societies:

American Institute of Electrical Engineers.

Society of Automotive Engineers.

Society of American Military Engineers.

American Society for Testing Materials.

American Institute of Weights and Measures.

The Aeronautical Society of America.

American Engineering Standards Committee.

American Welding Society.

He was also a member of the Welding Wire Specifications Committee of the American Bureau of Welding.

At a meeting of the Executive Committee of the American Welding Society held in the Engineering Societies Building, New York, N. Y., on the 5th day of March, 1929, the following resolution was adopted:

WHEREAS: the Executive Committee of the American Welding Society has learned with profound sorrow of the sudden death on Jan. 30, at his home in Pennington, N. J., of Harold J. Horn, a charter member of the American Welding Society, and

WHEREAS: in the death of Harold J. Horn, the American Welding Society has lost a faithful member and active worker for the advancement of the welding industry; therefore be it

RESOLVED: that the members of the Executive Committee of the American Welding Society hereby express their deep regret and sense of loss in the death of Harold J. Horn, and their appreciation of his services to the American Welding Society, and further be it

RESOLVED: that these Resolutions be spread upon the records of the Society and a copy sent to the J. A. Roebling's Sons Company, as an expression of our mutual loss and sympathy.

F. T. Llewellyn,
President.

Structural Welding Data

(Reprinted from March 7, 1929, issue Engineering News-Record)

Steady accumulation of data on the performance of fusion-welded structural parts promises well for the progress of the new art involved. An interesting addition to test facts is made by the results obtained with heavy plate connections as reported in this issue. Connections of this type are at first glance not very attractive subjects for welding, as any lack of uniformity might be expected to have an unfavorable effect by virtue of the irregular tearing action that can develop. The satisfactory character of the results is reassuring. The tests further illustrate anew the practical equivalence of a pair of weld beads and a rivet line of normal arrangement even in parts of large size. They tend to show that welded connections are available for practical consideration in massive special structures of complicated assemblage. As new data thus are brought together, the background of empirical fact on which so diversified an art as steel construction necessarily rests is extended most usefully. Sound development of welding depends on due continuance of the process.

Welding Symposium

Lehigh University, Monday, April 8, 1929.

PROGRAM

MORNING SESSION

10 a. m. to noon—Auditorium, Drown Hall.

Welding Operations and Their Practical Results, by F. T. Llewellyn, president, American Welding Society.

Followed by general discussion in which all are invited to participate.

AFTERNOON SESSION

1 to 4 p. m.—Fritz Engineering Laboratory.

Tests of Welded Specimens, as follows: Electric Pressure Butt Welding, Atomic Hydrogen Arc Welding, Electronic Tornado Welding, Arc Welding, Spot Welding (tension test), Automatic Metallic Arc Welding.

1 to 4 p. m.—Physics Lecture Room, Physics Building.

Demonstrations of Industrial Welding Apparatus,* as follows: Oxy-acetylene Welding, Thermit Welding, Oxygen Lance Cutting, Atomic Hydrogen Arc Welding.

1 to 4 p. m.—Welding Laboratory, Williams Hall.

Demonstrations of Industrial Welding Apparatus,* as follows: Automatic Arc Welding (two types), Electric Pressure Butt Welding, Spot Welding.

4 p. m.—Fritz Engineering Laboratory (all groups together).

Test of Full-Sized Welded Specimen, in 800,000-lb. compression machine. Oxygen Lance Cutting by driving a hole down the center of a steel billet, 6″ x 6″ x 24″. An attempt will also be made with the oxygen lance to cut steel covered with concrete.

4.45 p. m.—Swimming Tank, Taylor Gymnasium.

Under-Water Metal Cutting. The Under-Water Metal Cutting Corporation will give a demonstration by one of its experts in diver's costume of cutting steel plate under water by a combination of electric arc and oxygen lance. Owing to the gallery and standing room around the swimming pool, everyone will have an opportunity to see this demonstration.

*The demonstration of welding apparatus will be made by representatives of the manufacturers of the equipment.

EVENING SESSION

8 p. m.—Auditorium, Drown Hall.

Recent Scientific Progress in Welding. Introduced by Dr. Peter P. Alexander. Discussion continued by representatives of manufacturers of all different types of welding equipment.

New Building Code Allows Use of Welding

(News Release)

Thirty-eight municipalities on the Pacific Coast now have sections in their building codes covering the welding of buildings, according to an item in the General Electric Review for April. These cities, now operating under the regulations laid down by the Uniform Building Code, have followed the lead of Sacramento and Alhambra, which adopted that code late in 1927. They are as follows:

Sacramento, Cal.; Alhambra, Cal.; Fontana, Cal.; Redlands, Cal.; Oceanside, Cal.; San Bernardino, Cal.; Laguna Beach, Cal.; Pomona, Cal.; Fresno, Cal.; Piedmont, Cal.; San Rafael, Cal.; Coronado, Cal.; El Monte, Cal.; Ontario, Cal.; San Jose, Cal.; Visalia, Cal.; Fullerton, Cal.; San Francisco, Cal.; Pittsburg, Cal.; Claremont, Col.; Walnut Creek, Cal.; Tulare, Cal.; National City, Cal.; San Fernando, Cal.; Livermore, Cal.; Berkeley, Cal.; Martinez, Cal.; Compton, Cal.; Corcoran, Cal.; Madera, Cal.; Eugene, Ore.; Klamath Falls, Ore.; Shreveport, La.; Monroe, La.; Meridian, Miss.; Eldorado, Ark.; Prescott, Ariz.; Tucson, Ariz.

According to the new building code section for these cities, it is now legal for the Commissioner of Buildings in each place to grant, in the same manner as for riveted frames, permits for the erection of electrically welded steel building frames also.

Section 2710 of the Uniform Building Code authorizes the use of welding and sets forth the essential elements needed by engineers and architects in working out the designs for welded joints in steel beams and columns used in building construction.

The Pacific Coast Building Conference is an organization whose members are the building inspectors and commissioners of buildings, banded together to secure the adoption of a uniform building code. As a result,

engineers and architects who design buildings, and contractors who build them, may have but one type of code to conform to instead of a different code in each place.

In addition to the list of names given, there are many cities in which the code is either now being adopted or the ordinances of adoption are being prepared. In the eastern section of this country, various organizations have been at work for some time on a building code incorporating a section covering welding.

SECTION ACTIVITIES

Chicago

On Friday evening, March 1, the Chicago Section held its meeting in the auditorium of the Engineering Building. The subject for discussion at the meeting was "The Welding of Pipe in Buildings." Invitations had been sent to local heating contractors and to members of the local steamfitters union, among whom a very active interest in welding has been aroused. The attendance was well over one hundred and fifty and the discussion did not end until after eleven o'clock —a record for this section.

The meeting was opened with a very interesting two reel film of the Gas Products Association which dealt with welded pipe installations in a most comprehensive manner. The chairman called on J. I. Banash, consulting engineer for the International Acetylene Association, who spoke at some length on the safety, long life and economic aspects of the welded installation. From among the audience considerable data were presented by experienced engineers. T. M. Hamer of the Air Reduction Sales Company outlined a procedure for the training and testing of welders in a thorough fashion. Some of the other technical aspects of the subject were dealt with by Fred. C. Outcault of the Linde Air Products Company. He gave various data on different installations and tests of completed systems and the many types of pipe joints.

W. C. Swift, research engineer of the American Brass Company, outlined some of the developments of the welding of brass and copper pipe for residence and building installation. Spirited discussions followed the presentation of these talks.

Detroit

On Wednesday evening, March 20, the Detroit Section held a most interesting meeting. Mr. Outcault of the Linde Air Products Company gave an illustrated lecture on "Welding of Power Plant Piping." Motion pictures were shown on "Oxwelding and Cutting."

Northern New York

The Northern New York Section held its monthly meeting on Feb. 21. H. A. Woofter of the Swift Electric Welder Company gave a lecture on resistance welders and resistance welding applications. His talk dealt with some of the history of welding as well as applications of the present time. There were numerous slides shown which illustrated the applications of this form of welding and many of the welding machines.

Emphasis was placed on the importance of resistance welding in industry because of the high rate of production made possible by its use.

Philadelphia

The Philadelphia Section will hold its April meeting on the 15th. J. W. Meadowcroft, assistant works manager Edward G. Budd Manufacturing Company, will be the speaker. He will speak on "Welding Used Extensively in the Production of Sheet Metal Products." He will also show slides and two reels of film. This promises to be a very interesting meeting.

New York

The March meeting of the New York Section was held on the 8th, at which were present some four hundred members of the Society and other engineering bodies, including American Institute of Architects, American Institute of Steel Construction, American Institute of Civil Engineers, Construction Club of New York, Inc., New York Building Congress, Structural Engineers Society of New York. A. Vogel of the General Electric Company, presented an excellent review of

the "Applications of Arc Welding in Structural Work." He dealt with the fundamentals of welding, the design features involved and illustrated his talk with a number of slides showing practical applications of welding in the structural field. Considerable discussion followed the presentation of the paper by a number of prominent authorities in the structural field.

The May meeting, scheduled for the 7th, is to be a joint meeting with the local section of the American Society for Steel Treating. Two papers will be presented, one of them by W. L. Warner of the General Electric Company on "Some Metallurgical Aspects of Atomic and Other Electric Welding Processes," and the other by W. B. Miller of the Union Carbide and Carbon Research Laboratories on "Metallurgical Studies of Welds in Alloy and Other Special Steels."

Portland

The Portland Section held its monthly meeting on the 19th of February. Through the courtesy of Brown Bros. Welding Company of San Francisco two reels of film were exhibited, showing the installation of a pipe line for a hydroelectric project in the Feather River country. The field joints of this line were acetylene welded, and the pictures set forth the methods devised by Brown Bros. to accomplish their task through a rugged country.

The second portion of the evening's program consisted of views of unusually heavy pressure vessels welded by the Petroleum Iron Works Company of Sharon, Pa. This film was sent by this company, together with a paper describing the material shown on the screen.

On Jan. 29 a joint meeting was held with the Oregon Technical Council, which embraces the National Technical Societies having Oregon organizations.

The meeting was addressed by Frank P. McKibben, consulting engineer for the General Electric Company, on the subject "Electric Welding of Steel Buildings and Bridges." Mr. McKibben spoke of the extent to which the welding process has been used in the erection of steel structures, giving the reasons which have caused welding to be employed. These vary with the particular job—among them being savings in material, speed of erection, simplicity of design, ease in connecting to old structures and comparative noiselessness, which in some cases is an important consideration.

After describing in a general way the manner in which welded joints are made and the method by which the strength of the weld is ascertained, Mr. McKibben went into detail as to the methods used in the fabrication and erection of a steel frame structure for a West Philadelphia plant. Slides were shown illustrating the welding methods used in shop production and in erecting in the field.

Some 300 attended the meeting, among whom were a number of architects and designers.

EMPLOYMENT SERVICE BULLETIN

Opportunities.—The Society is glad to learn of desirable opportunities from responsible sources, announcements of which will be published wthout charge in the BULLETIN.

Services Available.—Under this heading brief announcements (not more than seventy-five words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period, names and records will remain in the office reference files.

Note.—Copy for publication in the BULLETIN should reach the Society's Office not later than the thirtieth of the month if publication in the following issue is desired. *ALL REPLIES should be addressed to the number indicated in each case and mailed to Society headquarters.*

SERVICES AVAILABLE

A-92. Acetylene and Electric Welder desires position. Have had two years' experience. Can give references.

Welding Duriron*

PEIRCE D. SCHENCK†

IN a large proportion of the chemical process industries Duriron equipment will be encountered, varying in form from such apparatus as fans, pumps or valves to large special castings.

Duriron is essentially an acid-resisting material and while not equally resistant to all corrosives, it is undoubtedly more nearly resistant to all acids than any other commercially available alloy.

The successful welding of Duriron requires clear understanding of the characteristics of the metal, although it does not differ radically from the principles involved in welding gray iron.

Duriron is really a silicide of iron—the composition being:

14.25 to 14.50 silicon
.80 to .90 carbon
.30 to .40 manganese .
Balance—iron

The coefficient of expansion is considerably higher than ordinary gray iron. The ultimate tensile strength is about half that of gray iron, and the resistance to impact considerably less.

The care required in preheating depends very largely on the size and shape of the casting. Large parts having any considerable area require very careful preheating in order to maintain uniform expansion. Small cylindrical castings, such as pipe, can be heated quite rapidly without danger from cracking. In any case the part to be welded should be heated to about 600 deg. C. or a bright cherry red. The actual welding operation is very similar to the welding of other ferrous materials.

Practically all of the welding which has been done on Duriron has been with the oxy-acetylene torch. Arc welding has not been used to any extent, and the discussion and suggestions apply entirely to torch welding.

Duriron will not oxidize to any extent under the oxy-acetylene flame. It is very fluid when melted and a very sound weld can be produced. It is only necessary to exercise care to see that the edges of the part to be welded are thoroughly molten while filling in with metal from the welding rod.

Duriron welding rod should always be used and is furnished of exactly the same composition as the castings. Excellent results have been obtained with the various fluxes used for cast iron welding.

Welding is largely used in the actual manufacture of Duriron equipment in the factory as well as for repair work and alterations to equip-

---

*Paper to be presented at Annual Meeting, A. W. S., April, 1929.
†President, The Duriron Co., Inc., New York, N. Y.

ment in the field. In the foundry it is, of course, impractical to use ordinary chaplets for supporting cores in casting as acid would eat through the chaplet very quickly and ruin the apparatus. Duriron chaplets are rarely used as the molten metal will not fuse with the cold chaplets. It is usually customary therefore to use sand core supports, deliberately leaving small openings in the castings which are afterwards easily and efficiently welded shut.

Occasionally castings which have lugs or other projections broken off in handling are salvaged by welding but by far the greater part of the factory welding operations consists in building up continuous pipe coils or intricate fittings where joints would be objectionable. Fig. 1 illustrates the type of fittings referred to—the welds having been made at the points shown by chalk marks.

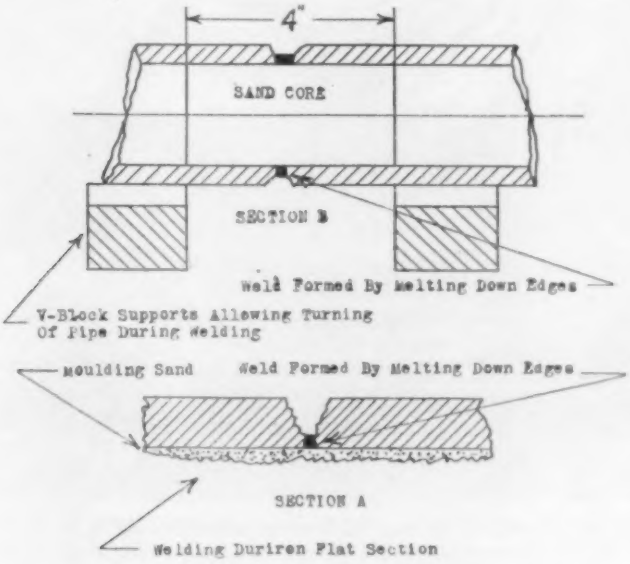

FIG. 1. REPAIRING DURIRON FITTINGS BY WELDING

The welded metal is of the same thickness as the original walls of the pipe, it having been demonstrated that such a weld properly made is as strong or stronger than the original pipe and, in fact, a thicker pipe wall at the point of welding is objectionable due to unequal expansion and would tend to develop cracks under high temperature operation.

The ordinary method of butt-welding is illustrated in Fig. 2. The pipes to be welded are placed in V blocks or jigs to maintain alignment. Dry sand cores, if available, are inserted in the pipe at the weld point to prevent excess metal accumulating in the bore. After preheating, the beveled edges of the pipe are melted down to form the start of the weld and at the same time welding rod is melted in until the weld is equivalent to the wall thickness of the pipe. Surplus metal should be wiped off with a

wire brush or asbestos pad and, if carefully done, the weld will scarcely be perceptible.

The question will naturally arise as to the effect of the welding operation on acid resistance. Theoretically, of course, there will be a difference in structure between the original pipe and the weld. As it happens, however, the metallurgical composition of the weld and the structure are so close to the original casting that there is no difference in the effect of acids. If anything, the weld usually contains slightly denser metal than the original casting and is less affected by corrosion.

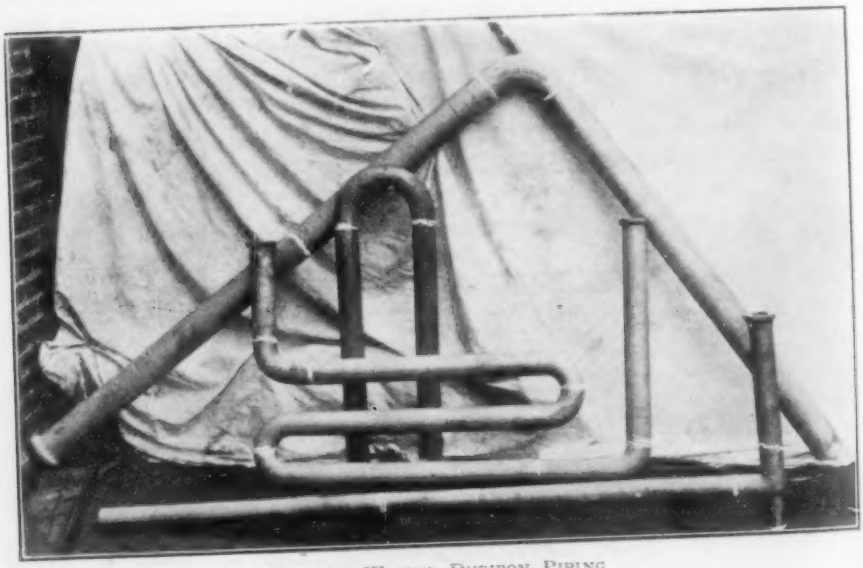

FIG. 2. WELDED DURIRON PIPING

The few welds which have ever failed in service have invariably shown signs of slag inclusions. Such slag inclusions can usually be detected by a careful welder and boiled out with a torch.

Successful welding of Duriron has been carried on at a few chemical plants for many years, while at other plants, if tried at all, was abandoned after the first unsuccessful experiment with the idea that Duriron was a highly special material and not susceptible to successful welding.

Curiously enough the welding of Duriron has been developed, we believe, in the United States to a far greater extent than the welding of similar alloys in other countries. Only recently one of the largest manufacturers of this type of material abroad was very much surprised to learn that it was being welded commercially in the United States.

Properly handled, Duriron is one of the easiest alloys to weld and it is often possible, thus, to salvage expensive equipment or to build up highly efficient special pipe layouts without joints, such as heating or cooling coils, steam jets, riser pipes, condensers and similar equipment.

Abstract of Paper on Welded Aluminum in the Chemical and Process Industries*

By W. M. DUNLAP†

Introduction:

THE outstanding requirement for materials to be used in the construction of chemical and processing equipment is that they shall resist the corrosive action which will be encountered in service. They must also possess sufficient strength to permit the construction of the apparatus without unduly heavy sections. In general, the deterioration from chemical influences is far greater than that resulting from mechanical causes.

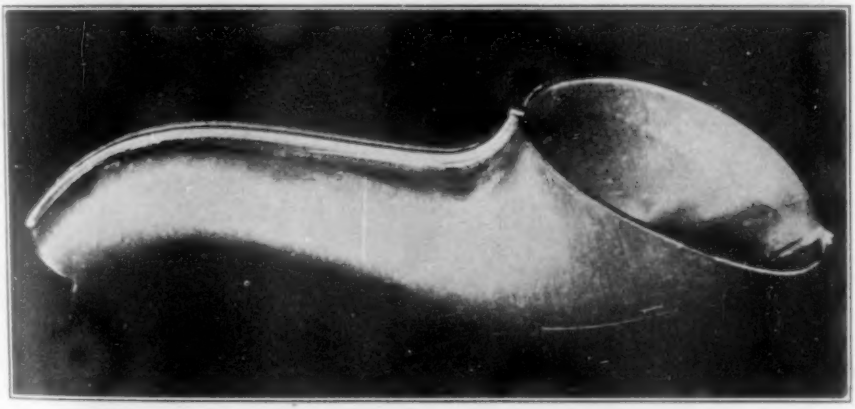

FIG. 1. TEA KETTLE SPOUT FORMED FROM 0.051-INCH ALUMINUM SHEET FLANGED IN PREPARATION FOR WELDING

No commercial material of construction is completely resistant to all reagents. The choice of the material for any installation is influenced by several factors, most of which affect the cost of installation. It is important to realize that the first cost is not the chief consideration, but rather the cost per month of service or the cost per pound of product. Figures will frequently show an advantage in favor of the installation of higher initial cost, when replacement, repair and maintenance costs, and loss due to idle equipment are considered.

On the basis of price per pound, aluminum compares unfavorably with some of the other metals commonly used in the chemical industries. However, when the price is made on the basis of price per unit volume

*Paper to be presented at annual meeting, A. W. S., April, 1929.

†Metallurgical Division, Research Bureau, Aluminum Company of America, New Kensington, Pa.

of metal or price per section of equivalent strength, the price differential is very materially decreased, due to the low specific gravity and the higher ratio of tensile strength to mass of metal possessed by aluminum. In comparison with some of the other corrosion resistant metals and alloys, aluminum has the advantage even from the standpoint of initial cost.

The effect of the material of construction on the quality of the resulting product is a factor which will frequently outweigh the considerations of slightly higher production costs. Aluminum salts are non-toxic. Aluminum is therefore, admirably suited for the production of materials

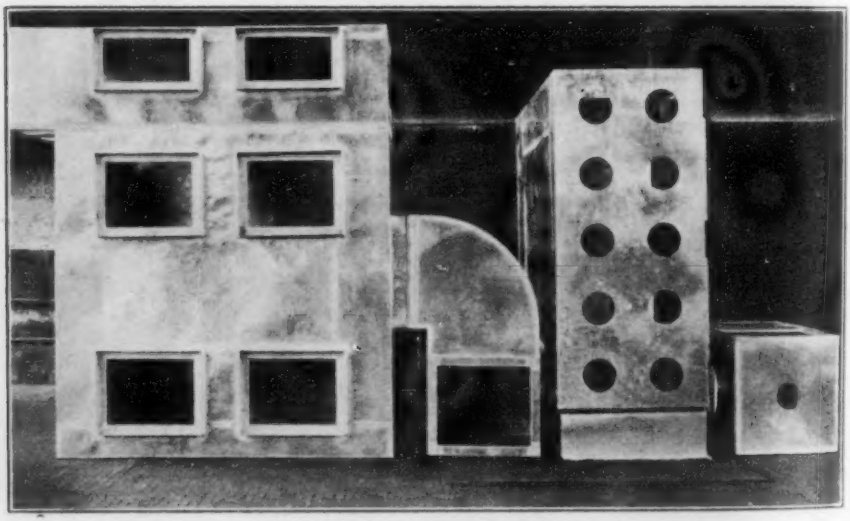

FIG. 2. WELDED ALUMINUM DRYING TANK FOR CELLULOSE ACETATE

which are used for human consumption. Aluminum salts are colorless. Materials which are graded on the basis of color command a higher price when prepared in aluminum equipment rather than in apparatus made from other metals whose colored salts lower the grade of the finished product.

Corrosion

As commonly used, the term "aluminum" includes light alloys of aluminum as well as the commercially pure metal. In considering resistance to corrosion and chemical action, it is necessary to take account of the purity of the metal. In general, the higher the purity of the aluminum the greater is the resistance to corrosion, especially in acid media.

In the literature relative to the corrosion of aluminum, occasional reference is made to failure of aluminum equipment due to chemical attack at the welded joints. This difficulty can be corrected, in part, by proper care in making welds. The metal in the weld is analogous to a casting and there is a tendency toward a difference in solution potential

between the wrought material and the cast material, which would cause electrolytic corrosion. It is sometimes possible to hammer the weld and the adjacent metal and thus produce a more nearly uniform condition throughout the apparatus. But even where this is not possible, careful

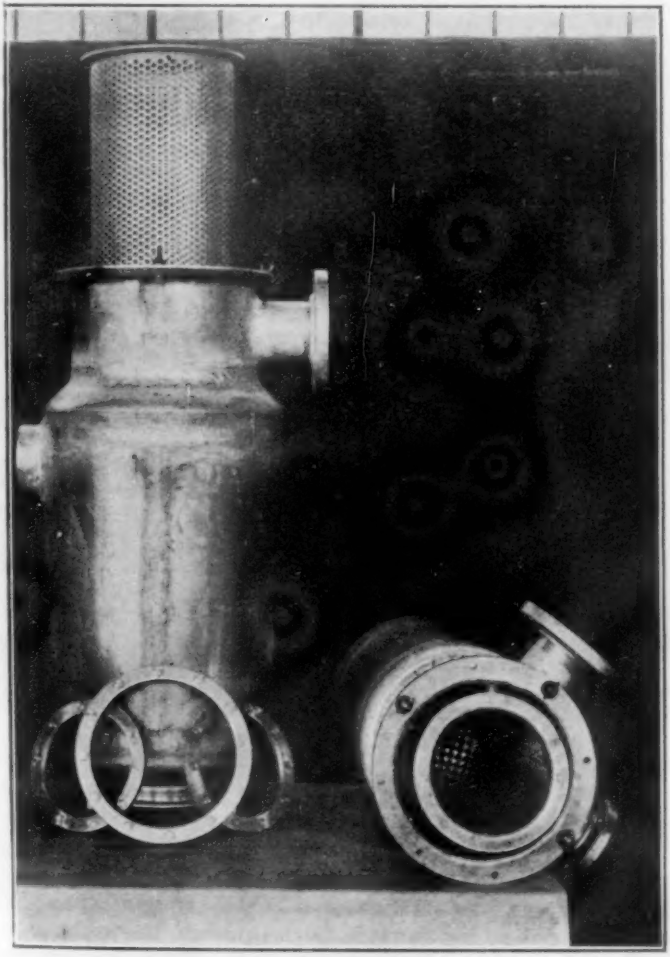

FIG. 3. WELDED ALUMINUM FILTER BAGS, GRASSELLI CHEMICAL CO.

workmanship in making and finishing the weld is effective in overcoming much of the difficulty which might otherwise be experienced.

A series of commercially pure aluminum specimens welded with commercially pure wire and 5 per cent silicon alloy wire was subjected to the corrosive action of a spray of 20 per cent salt (NaCl) solution for a period of six months. A similar series of specimens was subjected to

tap water corrosion for a period of 45 weeks. This tap water was a hard water of the following analysis:

Total solids	130	parts per million
Cl	11.4	parts per million
SO_3	47.8	parts per million
Ca	24.1	parts per million
Mg	4.4	parts per million
$CaCo_3$	0.0	parts per million
$Ca(HCO_3)_2$	40.2	parts per million
Si	0.8	parts per million
Al	1.5	parts per million
pH value	8.1	parts per million

A visual examination of the corroded specimens indicated that there was no appreciable difference in resistance to corrosion between welds made with commercially pure wire and 5 per cent silicon alloy wire. None of the welds showed any appreciable attack in either salt spray or tap water.

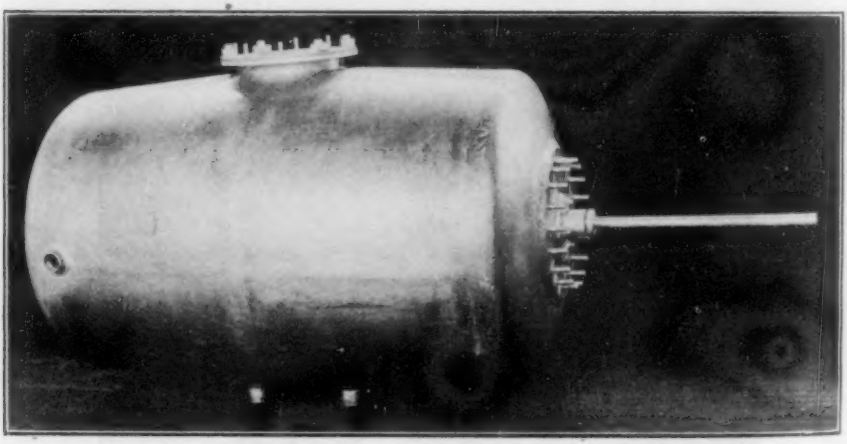

FIG. 4. WELDED ALUMINUM COOKER, POSTUM CEREAL CO.

There did not appear to be any appreciable difference in the resistance to corrosion between the torch side of the weld and the other side.

When aluminum is subject to corrosive reagents it is desirable that there shall be as little tendency toward electrolytic corrosion as possible. No other metal should be in contact with the aluminum and with the corrosive agent. If another metal is used, it should be insulated from the aluminum by some non-conducting material. Even this precaution is not always sufficient, since in some cases heavy metal salts will later be precipitated on the aluminum with the solution of an equivalent weight of aluminum. The precipitated heavy metal then forms with the aluminum an electrolytic couple which still further accelerates the corrosive action.

Strength of Welds

Some tests were made for the purpose of comparing the strength of welded commercially pure aluminum pipe with the strength of the orig-

inal unwelded material. Since the weld metal is in the cast state, the strength of a welded aluminum joint is usually considered as being equivalent to the strength of annealed material. However, such an assumption does not allow for possible defects in the welds.

Test samples were prepared from annealed 2S (commercially pure aluminum) and annealed 3S (commercially pure aluminum plus 1.25 per cent manganese) in ¾ in., 1 in., and 1¼ in. iron pipe size. All samples were approximately 18 in. long. The test samples were cut in half and then welded together. All welds were made in the plant according to commercial practice. The ends to be welded together were first chamfered and nicked in the usual manner. Commercially pure welding

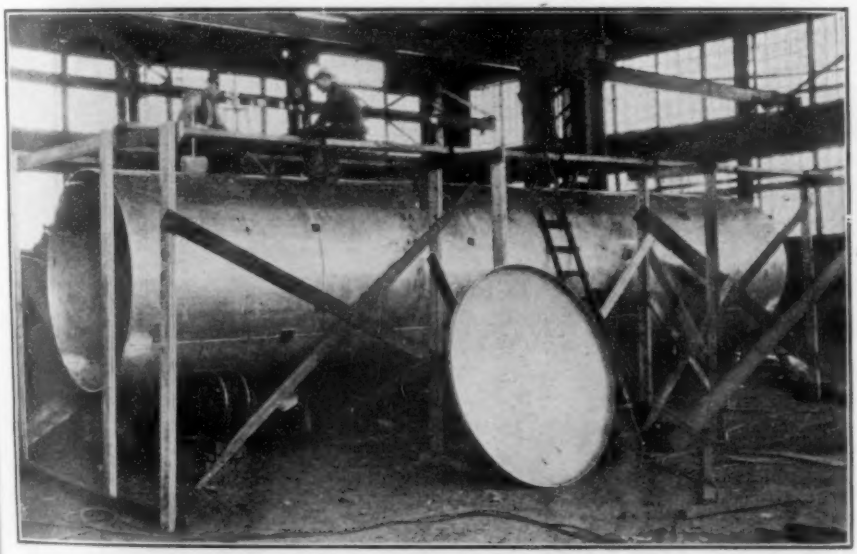

FIG. 5. WELDED ALL-ALUMINUM TANK CAR

wire, which runs from 99.2 per cent to 99.5 per cent aluminum, was used for all welds. The welds were not dressed, but left as made by the torch, slightly built up. Care was exercised during welding to get the two pieces properly aligned.

All samples were subjected to tensile and hydrostatic tests. The tensile tests were made by pulling the specimens in an Amsler testing machine with V-grips, using steel plugs in the ends of the tubes to prevent crushing by the grips. For hydrostatic tests, the ends of the tubes were threaded and one end capped while the other end was connected to a high pressure hand pump, using iron fittings. Internal water pressure sufficient to burst the sample was applied.

Three welded specimens of each size and kind were tested. In addition, two samples of each size and kind of the original unwelded tubing were tested so as to have a basis of comparison for the welded tubes. A summary of the results of these tests is given in the table.

Summary of Tensile Tests

Size	Sample	Condition	Per Cent Elongation 2"	Per Cent Elongation 8"	Tensile Strength, Lb./Sq. In.
3/4"	2SO	Original	46.3	34.2	14,340
*3/4"	2SO	Welded	46.8	32.0	13,435
1"	2SO	Original	54.5	36.6	12,650
1"	2SO	Welded	49.8	29.7	12,975
1¼"	2SO	Original	55.3	37.1	13,150
1¼"	2SO	Welded	53.5	31.8	13,175
3/4"	3SO	Original	45.8	27.3	16,680
3/4"	3SO	Welded	41.3	23.9	16,665
1"	3SO	Original	53.5	35.3	14,900
1"	3SO	Welded	49.7	30.8	15,010
1¼"	3SO	Original	55.3	34.8	15,515
1¼"	3SO	Welded	53.0	31.2	15,535

*One of three samples failed at weld.

Summary of Hydrostatic Tests

Size	Sample	Condition	Bursting Pressure, Lb./Sq. In.
3/4"	2SO	Original	2,850
3/4"	2SO	Welded	2,930
1"	2SO	Original	2,800
1"	2SO	Welded	2,800
1¼"	2SO	Original	2,200
1¼"	2SO	Welded	2,280
3/4"	3SO	Original	3,950
3/4"	3SO	Welded	3,950
1"	3SO	Original	3,200
1"	3SO	Welded	3,330
1¼"	3SO	Original	2,700
1¼"	3SO	Welded	2,770

The summary of the test results given above shows quite definitely the results obtained.

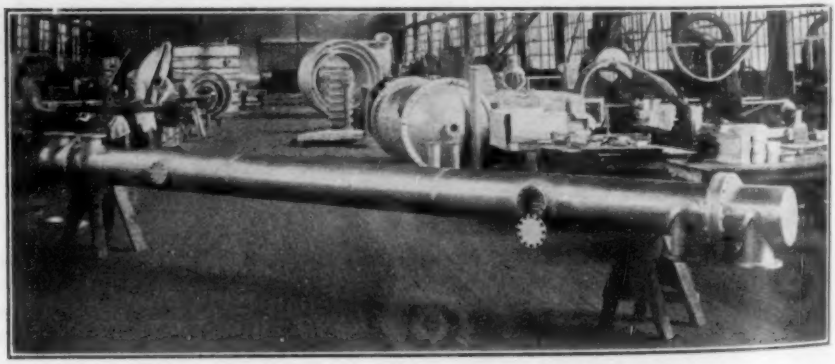

FIG. 6. WELDED ALUMINUM EQUIPMENT FOR POWDER PLANT

In the tensile tests, the stress was applied in a direction perpendicular to the welded joint, thus tending to pull the weld apart. In the hydrostatic tests the opposite is more or less true, that is, the major stresses, which again are in tension, are applied in the direction of the welded

joint. In this test there is also a secondary tensile stress applied in a direction perpendicular to the welded joint. This secondary stress is only about half as great as the primary stress, according to the usual formulæ for stresses in the walls of cylinders subjected to internal pressure.

It will be noted from the summary table of tensile tests that there is practically no difference between the tensile strength of the welded tubes and the original tubes. Moreover, only two out of a total of 18 welded samples failed in the welds. This would indicate that the weld is actually stronger than the original tube, and it is reasonable to expect this, since the tube wall is somewhat heavier at the weld due to the building up of metal in the process of welding. Furthermore, the tubes were in the soft or annealed condition.

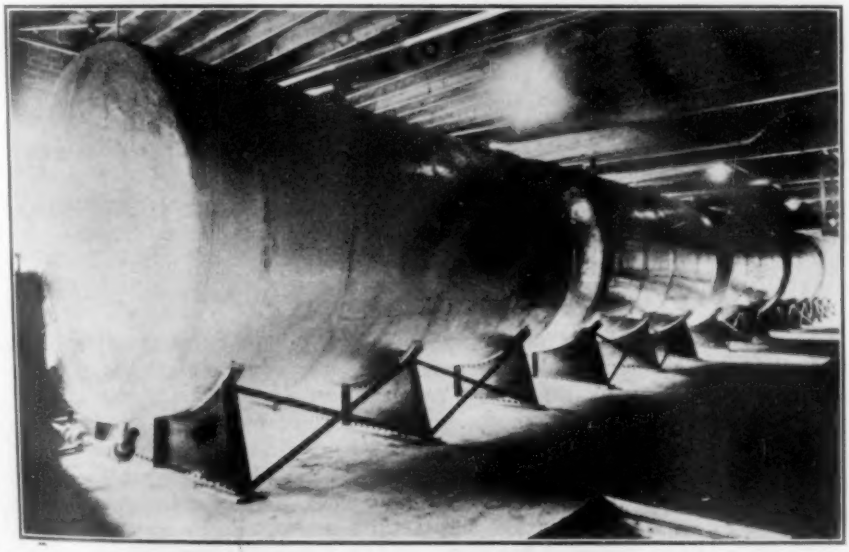

FIG. 7. ACETIC ACID TANKS OF WELDED ALUMINUM

The summary table of hydrostatic tests also indicates that the welded and original samples have practically the same strength. In this set of tests none of the failures occurred at the welds, but in every case the pipe burst between the weld and one end of the sample. This again indicates that the weld is stronger than the original sample. In the hydrostatic tests the building up at the weld apparently had the effect of a stiffening rib around the tube.

It should be remembered that the original tubing used in these tests was dead soft, or very nearly so, and that the above discussion would, of course, not hold for intermediate or hard temper tubing. While this investigation might have been extended to cover the harder tempers of tubing, there was some question at this time as to whether the value of such additional information would justify the increased expense necessary. For many uses of welded aluminum tubing where the

material is subjected to elevated temperatures, the tubing becomes annealed in time, and for such cases, the results of these tests are directly applicable. For other uses of intermediate and hard tempers of aluminum tubing where the material is not subjected to heat, it would seem that the strength would, in most cases, be governed by the strength of the tube immediately adjacent to the welded joints where the material becomes annealed from the heat of welding, again making the results of these tests applicable within reasonable limits.

EDITOR'S NOTE:

The original article by Mr. Dunlap also includes complete information as to the welding of aluminum covering such items as welding apparatus, flame, fluxes, welding wire, preparation of the edges, supporting the work, buckling produced by welding, torch manipulation, welding sheet aluminum and finishing welds. This information was previously published in a comprehensive paper on the welding of aluminum and its alloys by Mr. Dunlap in the January, 1929, issue of the JOURNAL OF THE AMERICAN WELDING SOCIETY. *It is therefore not reproduced at this time. Readers are requested to refer back to the January number for this information.*

The Production of Ductile Welds in Nickel and Monel Metal*

By N. B. PILLING† and T. E. KIHLGREN†

THE growing use of nickel and nickel alloys in applications such as those of the chemical and process industries in which resistance to corrosive action is an important requirement, inevitably focusses attention upon the jointing methods which are available. Welding is a particularly attractive method of fabrication owning to its flexibility and the ease with which tight seams can be made. A considerable advance has been made in methods for welding nickel and its principal commercial alloy, monel metal, within the last 10 years and the many engineering applications which have consumed a large tonnage of metal and ivolved successful fusion welding is in striking contrast to the common textbook assertions that nickel is unweldable by fusion methods, and cautioning the welder that great skill and experience are necessary in working with the high nickel-content alloys. While it is true that these metals are not as easily handled as steel and other metals ordinarily falling within the welding engineer's experience, the purpose of this brief paper is to demonstrate that such difficulties as have been experienced are now largely under control, that the success of welds made with these two metals is highly dependent upon details of welding method, and to disclose what these successful methods are.

The key to the production of good welds lies in the deposition of metal which is metallurgically sound. Many special details of manipulation are important in applying welding to the construction of welded equipment

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*Paper to be presented at Annual Meeting, A. W. S., April, 1929.

†The International Nickel Co., Inc., Bayonne, N. J.

but are beyond the province of the present discussion, which is concerned with the extent to which the quality of nickel and monel metal as laid down by several welding methods depends upon the conditions of welding. An entirely adequate discussion of these fabricating details has been given by Crawford and Schoener* and is covered by the working instructions issued by the International Nickel Co.

Nickel is a metal which is metallurgically far more sensitive to the conditions under which it is melted (these general remarks apply with equal force to monel metal and other high nickel-content alloys) than are iron, steel or many of the high alloy content iron alloys. Sulphur, even in minute traces, is highly detrimental to the strength and toughness of nickel and it must therefore be rigidly controlled, both as to the original content (nickel is produced from a sulphide ore) and to the possibility of absorption from other substances with which it comes in contact when heated. Fused nickel absorbs both carbon and oxygen with avidity and if taken up in excess the former appears as flake graphite and the latter as an oxide structure, both of which embrittle the solid metal. Nickel is also prone to absorb various gases while molten and later eject them during freezing to form blowholes and other unsoundness. The metallurgical steps whereby this temperamental metal is reduced to docility are complicated, but it sufficies to say that the malleable nickel sheet or wire which confronts the welder as material to be welded contains small but essential quantities of highly reactive elements, including carbon, silicon, manganese and magnesium. The physical quality of the metal depends in no small measure upon the retention of these auxiliary elements.

In fusion welding, the very nature of the operation requires a high rate of energy input at the weld in order to confine the fusion locally and this unavoidably results in superheating the melted metal and exposing it under highly unfavorable conditions to reaction with the surrounding atmosphere. The normal result of such exposure, in the absence of protective measures, is the loss by oxidation of the necessary auxiliary elements, followed by the absorption of certain gases and development of porosity on freezing. The degree to which this occurs depends to a very considerable extent upon the method and circumstances of fusion. The skill of the welder comes in by so performing his fusion as to prevent the loss of these elements and at the same time avoid picking up other damaging substances. While development on the part of the principal producer of nickel has resulted in the production of sheet and wire more amenable to fusion welding than heretofore, there are other important aids for the welder and it is with these that we are concerned.

Method of Test

There has been some discussion recently regarding proper methods of determining the physical quality of test welds, and it has been suggested† that owing to the non-uniformity of a welded joint and the transverse buttressing action of the weld section, the simple tension test is

*Welding Monel Metal and Nickel; C. A. Crawford and J. C. Schoener, Acetylene Journal, XXIX, p. 365 (1928).

†W. B. Miller, Gas Welding of High-Chromium Corrosion Resistant Alloys; Proc. Am. Soc. Testing Materials (1928).

unsuitable and that failure to show a good tensile elongation across the weld does not necessarily indicate a lack of ductility within the weld metal. The proposal has been made that a bend test may disclose a satisfying degree of ductility in welds which show an inferior elongation in the tension test. We have found, on the contrary, that whenever sound welds have been obtained, which also showed high strength, these welds almost without exception would show an excellent elongation when broken in tension, and believe that the simple tension test is entirely adequate to demonstrate strength and ductility properties.

A good weld in nickel or monel should be sound, strong and ductile, and of these three qualities soundness seems to be most fundamental. Unsoundness may originate in unskillful welding, as laps or other imperfections of a physical nature, or may result from the separation of gas from solution during the freezing of the metal. The latter is probably closely related to the detailed composition of the metal, the temperature reached in welding, the nature of the atmosphere in contact with the fused metal and the presence of reactive substances supplied externally as in fluxes or coating materials. Soundness—that is, freedom from gas holes—is considered to be the most important factor in nickel and monel welding for the reason that other desirable properties seem to be directly determined by it. That is, soundness, high strength and high ductility all go rather consistently together and any loss in one is usually associated with corresponding losses in the others. The reason for this close connection is obvious on reflection, for the breaking load in the tension test will depend upon the smallest effective load-bearing cross-section, and the elongation will tend to become more highly localized within the weld as the proportion of voids, and consequent stress concentration, increases.

The nickel (Grade A) and monel metal were taken from selected heats chosen as representative of the grade of these metals commercially available at the present time. They were in the form of hot-rolled, annealed plate $\frac{1}{8}$ in. thick, sheared into coupons 3 in. x 6 in. The test welds were all double-seamed butts, made by uniting the 3 in. sides of two coupons, and in all cases the weld during fusion was backed up by a graphite block. The tension test specimen was prepared by milling off the two adges of the weld about $\frac{1}{2}$ in. leaving a reduced section 2 in. wide and 5 in. long. All the present welds were made with matched filler and plate, i. e., with plate and wire cut from the same stock. They were tested in the "as welded" condition, without being subjected to heat treatment or to any mechanical improvement, as by hammering.

It should be particularly noted that the tension tests had two objectives requiring two different test specimens. In demonstrating the effect of welding technique the excess weld metal was carefully dressed off as much as possible, leaving the welded section uniform in thickness. This usually forced the break to occur in the weld and allowed calculation of the actual breaking stress of the weld metal. In this case the stress at fracture has been computed for both plate and weld sections. In another series in which the strength of the joint as a whole was in question, the weld metal was left in full section and the breaking stress computed to the plate section.

Metallic Arc Welds

With the metallic method of welding, in which the filler wire also serves as one of the arc electrodes, the superheating of the fused metal, particularly that forming the arc crater on the wire, is so great that not only is chemical reactivity between metal and atmosphere intense, but the content of magnesium, small though it is, may pass off by distillation. Arc welds made in the open air without a protective atmosphere are almost certain to be highly porous and exceedingly brittle. A protective atmosphere which will displace air, and introduce no other detrimental gas is an essential requirement for the production of sound arc welds, and one way of conveniently achieving this is by the use of a suitable coating on the electrode wire. A good coating of this sort was described by Merica and Schoener* involving the use of a powdered magnesium-manganese-silicon alloy, and operating on the theory of supplying additional magnesium to the fused metal to make up for that lost. Using this coating, Merica and Schoener were the first to produce ductile arc welds of monel metal, their tests showing a breaking strength of 47,100 lb./sq. in. with 9.7 per cent elongation. A more recent development along this line† employs a coating material containing titanium and calcium as active ingredients, proportioned such that the percentage of titanium present in the mixture is about four times that of calcium. The operating principle of this coating material is that the calcium, being highly volatile at arc temperature, forms a harmless vapor jacket displacing air from around the arc, while the titanium, resisting vaporization, persists as a highly reducing element in the fusion protecting it from oxidation. Other coating materials of a reducing nature, including silicon, calcium-silicon, mangnesium, manganese, vanadium, zirconium, borax, lamp-black and fusible silicate compounds have proved to be of slight value.

The titanium-calcium electrode coating may be prepared from ferro-titanium and calcium-silicon; the aluminothermic alloy containing 25 per cent Ti and the calcium alloy containing 35 per cent Ca are suitable, both being brittle enough to allow grinding to the required fineness (150 mesh.) The combined powders (1 part CaSi to 5 parts FeTi by weight) are mixed with a binder, preferably a gum-base varnish, and the coated electrodes allowed to dry before use. It is necessary that the thickness of this coating be adequate; a minimum thickness of .008 in. on $\frac{1}{8}$ in. electrode has been found desirable. This coating material, under designation "Inco Electric Welding Flux" is distributed by the International Nickel Co. to users of nickel and monel metal.

Table I following presents some tests of nickel and monel welds, contrasting the effects of bare and coated electrodes.

From these it will be seen that it is rather more difficult to obtain welds of high quality with nickel than with monel. This appears to be a very general truth, and may be expressed roughly, that nickel is more sensitive to abuse in welding by any method than is monel. That is, any departure from the conditions of welding which have been found best shows up as inferior weld quality sooner with nickel than with monel.

*Journal Am. Welding Soc., May, 1922, p. 13.
†U. S. Pats. 1,679,002 and 1,679,003.

Table 1—Metallic Arc Welds
(Dressed)

Metal	Electrode Coating	No. Tests	Tension Test Stress at Fracture, Lb./Sq. In. In Plate	In Weld	Elong. Across Weld, % 2"
Nickel	Unwelded plate	3	73,500		48.8
	Bare	4	7,000	5,600*	0.7
	Titanium-calcium	7	40,700	35,400*	8.0
Monel	Unwelded plate	3	79,300		42.6
	Bare	4	18,200	15,800*	2.5
	Magnesium-mangarese-silicon	6	62,200	53,100*	17.4
	Titanium-calcium	6	72,700	60,300	27.0

*Break in weld.

Carbon Arc Welds

In one important particular, the carbon arc method differs from the metallic arc. The filler wire no longer acts as one electrode of the arc, and in consequence the metal droplet does not reach the extremely high temperature that it does in the metallic arc. It is probable that the very marked superiority of carbon arc welds of nickel and monel metal is due to this colder operation, rather than to the change in arc atmosphere. It is highly necessary to coat the filler wire, and the titanium-calcium mixture has been found excellent, the general rules for its use being the same as with metallic arc welding.

Table 2 summarizes the tensile properties of carbon arc welds.

Table 2—Carbon Arc Welds
(Dressed)

Metal	Coating	No. Tests	Tension Test Stress at Fracture, Lb./Sq. In. In Plate	In Weld	Elong. Across Weld, % 2"
Nickel	Unwelded plate	3	75,400		50.6
	Bare	3	47,000	38,000*	6.8
	Titanium-calcium	5	60,300	50,500*	18.7
Monel	Unwelded plate	2	73,400		46.5
	Bare	6	47,100	36,200*	7.0
	Titanium-calcium	6	73,600	57,900	33.7

*Fracture through weld.

Oxyacetylene Welds

While the temperature reached in welding with the oxyacetylene torch is probably considerably lower than with the carbon arc, a difficult condition arises from the extremely oxidizing condition of certain portions of the oxyacetylene flame with which the fused metal may come in contact. Even with the flame adjusted for a slight "feather" of color, its strong oxidizing action results in the formation of a surface scum, largely of magnesium oxide, and in a strong inclination for blowhole formation. The scummy surface may become heavy enough to interfere with the flow of the metal and this sometimes tempts the operator to indulge in the use of fluxes. While it is very true that the fluidity of the fusion and perfection of penetration can be greatly improved by

fluxes such as boric acid and borax, they are apt to be over-active and by continually removing the oxide crust allow the oxidation of magnesium and other elements to proceed so far that metallurgical difficulty is encountered. This is particularly the case with nickel, and at times even short welds have cracked apart spontaneously on cooling, whereas welds with the same metal and similar in all respects except the use of flux have been of good quality. Over-fluxing also increases the liability toward gas precipitation and porosity in the finished weld. A good oxyacetylene weld in either nickel or monel should freeze quietly at the end of the seam leaving a broad, shallow pipe or depression. Any display of sparks or volcanics indicates unsoundness.

As ordinarily handled, the oxyacetylene torch is directed along the line of the weld to be made such that the expended flame gases are dissipated ahead of the weld. Under these conditions the molten weld metal freezes very quickly and close to the torch flame, aided probably by the inrush of cold air caused by the injector action of the flame jet.

Table 3—Oxyacetylene Welds
(Dressed)

Metal	Special Condition of Test	No. Tests	Tension Test Stress at Fracture, Lb./Sq. In. In Plate	In Weld	Elong. Across Weld, % 2"
Nickel	Unwelded plate	3	75,400		50.6
	Normal	5	45,900	39,700*	9.9
	Boric acid flux	6	32,400	27,300*	5.0
	Flame reversed	5	58,300	45,000*	17.3
	Borated acetylene	6	59,500	47,100*	20.4
	Borated acetylene, flame reversed	4	58,800	48,000*	20.4
Monel	Unwelded plate	2	73,400		46.5
	Normal	6	47,600	44,300*	8.3
	Boric acid flux	6	59,000	47,400*	16.2
	Flame reversed	6	70,900	52,700	33.8
	Borated acetylene	6	71,200	52,300	33.8

*Fracture through weld.

This condition of rapid freezing is made manifest by sharp, crescent-shaped ripple markings on the weld surface, indicating that the edge of the freezing metal is in contact with the depression under the flame jet. It is apparent that any gas discharged from the fusion during freezing has a poor chance to rise out, but tends to remain as blowholes. The test condition designated in table 3 as "normal" exemplifies this use of the torch. Under these conditions welds made with either nickel or monel are not so good and show elongation values under 10 per cent.

Reversing the direction of the torch flame such that the expended gases bathe the recently deposited metal delays the freezing of the weld metal and improves its soundness considerably. The effectiveness of this simple maneuver in improving the quality of the deposited metal is clearly shown in table 3.

While delaying the rate of freezing is helpful, we have found another more convenient way of improving the soundness consisting in imparting a mild but controlled fluxing action to the flame itself, accomplished by introducing a gaseous boron compound, into the acetylene supply. This

can be easily done by a method which will be described later. The borated oxyacetylene flame is colored green but no difficulty in adjusting its proportions is encountered. Fluxing by this means has the obvious advantages that the flux follows the flame, is always present where most needed and is subject to close control. With both nickel and monel it was possible to make the weld at a faster rate with the borated flame than with the ordinary flame, owing to the somewhat easier flowing quality which the flame imparted. It is interesting to see that combining the reversal of flame with the borate method gives results with nickel which are practically identical in quality with those made with borate alone. It seems likely that the beneficial action in both cases has a common origin in the elimination of blowholes in the nickel weld. In the first case this is achieved by more perfect clearance of the fusion from gas which has already precipitated; in the second the mild fluxing action of the flame allows the weld to be made more rapidly and hence at a lower temperature, whereby the opportunity for the formation of the offending gas is lessened.

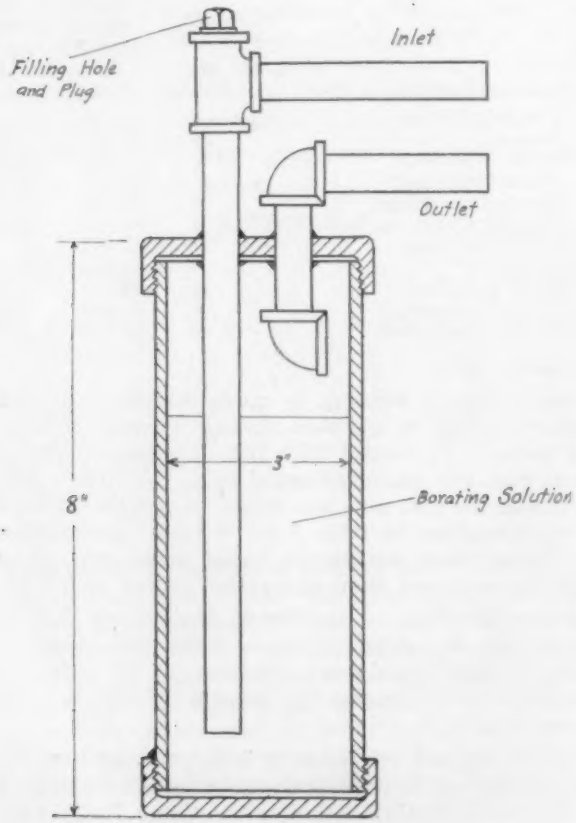


FIG. 1

Borating the acetylene supply is a matter of little difficulty, and can be done by bubbling the gas through a solution of the boron compound. The proportion taken up by the acetylene depends upon the kind of solution, and a suitable one for use with nickel and monel is ethyle borate in alcohol. This can be made by dissolving finely powdered boric oxide or fused boric acid in denatured grain (ethyl) alcohol, taking care to have a good excess of undissolved powder. Fig. 1 shows a sketch of a borating bubbler which can be constructed from pipe fittings by any welder and is sufficient for the purpose. This should be inserted in the acetylene supply line between the reducing valve and the torch.

Cracking of Welds

Both nickel and monel metal are fragile at a temperature just below their freezing points and if put under stress at this temperature will easily break. When a welded seam is remelted, as in building up or reseaming the weld, a crack may form down the center of the weld passing entirely through the seam. This occurs because at the edge of the plate where the fusion is begun the entire tensile load due to the thermal expansion of the plate metal is borne by the freshly solidified metal, and once a crack forms it is self-propagating, following the torch closely. If the simple precaution is observed, never to start refusion at an exposed edge, but leave an inch or two of cold metal to bear the thermal stress, freedom from this kind of cracking is assured. All of the test specimens which have been discussed were reseamed in this way successfully.

Cracking may also develop, even on the first seam, if the weld is overfluxed. In this case the cause appears to be an excessive dissipation of magnesium from the molten weld metal, so that the now well-known embrittlement* from the minute sulphur content of the metal occurs. The remedy for this is obvious.

Raw Welds

All of the preceding tension tests have been made on butt welds in which as much as possible of the excess weld metal was dressed off, concentrating attention on the quality of the weld metal itself, rather than on the joint as a whole. A few test results may now be of interest to show the strength properties of simple butt-welded joints in ⅛ in. thick nickel and monel metal plate, made by the best operating methods previously disclosed.

Table 4—Strength of Raw, Double-Seamed Butt Welds, 1/8" Plate

Metal	Welding Method	No. Tests	Breaking Stress in in Plate, Lb./Sq. In.	Elong. Across Weld, % 2"	Joint Efficiency, %
Nickel	Metallic arc, coated	4	74,000	32.1	98
	Carbon arc, coated	3	67,800	30.0	90
	Acetylene borated	4	72,000	34.5	96
Monel	Metallic arc, coated	5	73,000	34.7	99
	Carbon arc, coated	4	72,400	33.5	98
	Acetylene, borated	4	70,900	40.5	96

*P. D. Merica and R. G. Waltenberg, Bureau of Stds. Technologic Paper 281 (1925).

The arc welds were all made using the titanium electrode coating previously described, and the acetylene welds were all made with borated acetylene, the welding procedure in other respects being normal.

In every case these full-section welds broke outside of the weld in the adjacent plate section which had been heated by the welding operation. It is a matter of no difficulty, therefore, to obtain welds by any of these methods in which the weld-metal section is stronger than the plate, and with overall joint efficiencies of 90 to 95 per cent.

Summary

Both nickel and monel metal are excellently adapted for fabrication by fusion welding methods; the production of welds which are strong, sound and ductile requires adherence to suitable methods of welding rather than the exercise of a high degree of manual skill. Details of good methods have been discussed and the great extent to which the quality of welds in these two metals depends upon welding method illustrated with tension test examples.

Of the arc methods, the carbon arc yields a weld metal superior in strength and soundness to that laid down by the metallic arc and is preferred when possible. Welds of excellent quality can be produced by the acetylene flame provided the fluxing conditions are controlled. While the three welding methods yield rather different qualities of weld metal, the specific strength of the weld metal is sufficiently high so that the excess in thickness of the weld ordinarily suffices to bring its total strength well above that of the plate. The strength of such butt joints is from 90 to 95 per cent that of the rolled plate.

Training Welders at Dunwoody Institute*

M. Reed Bass†

FOURTEEN years ago Dunwoody Institute began the training in evening classes of oxy-acetylene welders and the work has been maintained from year to year, constantly increasing since that time. The Institute, which is located in Minneapolis, is a privately endowed school, established under the will of Mr. William Hood Dunwoody. Tuition is free to residents of the State of Minnesota. Certain special fees are required for the various courses but an effort is made to keep these to the minimum. Those who attend the school from other States pay the entire cost of the instruction. Day, part-time and evening classes are operated. In these evening classes training is given for sixty-five different occupations, one of which is welding.

When the Institute was established in 1914 a survey was made of the occupations in the city of Minneapolis for the duties of which workers needed training. It was seen at once that one of the most promising of these was welding. As a result, welding was one of the earliest

*Paper to be presented before Annual Meeting, A. W. S., April, 1929.
†Assistant Director Dunwoody Industrial Institute, Minneapolis, Minn.

classes established in the evening extension school, a school, incidentally, which is open only to boys and men who are employed in trade and industries.

At the outset, training was given in oxy-acetylene welding only, but later electric arc welding was added. One class was offered for twenty pupils. During the present school year five classes have been offered, which have served a total of nearly two hundred students. From the outset, four hours of instruction were given during an evening session, two hours being devoted to job work and two hours to class work. Now three and one-half hours are devoted to shop work and thirty minutes to class work. This change has come about because the school realized from experience that beginners in welding work need more practice and not so much theory.

Several problems have been faced constantly by the school from the start. One of the most important of these is the selection of a competent instructor. Obviously, he must be a man with outstanding experience and success as a welder himself. Welding is a practical proposition and cannot be taught by any man who does not have the skill and practical knowledge which a tradesman must use in this line.

Obviously, the instructor must be master of the use of welding, both by the oxy-acetylene method and by the electric arc method. Instruction on any given night is individual. At the present time opportunities are open for men to get training according to their wants in the welding of steel, cast iron, aluminum, malleable iron, copper and brass. Since men wanting the experience with different kinds of material are present on the shop floor on any night, the instructors who serve them must, of course, be able to give them individually what they need.

In addition, progress in the use of welding in new ways has brought demands on the school to furnish training for men in all such specialties as steam fitting, plumbing, airplane construction, and the like. For these, special classes are usually arranged with specially qualified instructors.

Every effort is made to confine this instruction in welding to workers who are engaged in lines of employment for which the ability to do welding work constitutes an additional asset. Carpenters, for example, are not eligible for admission, nor bakers, but people from all such lines as the following: automobile, machinists, tool makers, sheet metal workers, boiler makers, blacksmiths, plumbers, steam fitters and aviation repair men.

The records of the school indicate that probably no work which it has offered in the various lines it provides has been so successful in giving large numbers of students an additional wage-earning asset upon which they have been able to realize almost immediately. The result of all this has been that, as was indicated above, the enrollment has grown very rapidly and the resources of the school have been pushed to the limit in order to provide the services needed. Usually there is a waiting list of prospective students.

Another measure of the growth of the work is furnished by the increase in the equipment used. At the outset ten torches were available;

now the number is thirty-four and they are kept busy virtually every night of the seven months' session of the evening school.

At the present time only one arc welding machine is available, which provides instruction for two men per night, but the school is contemplating increasing its equipment so as to serve a minimum of twelve men per night.

One feature which should be discussed here is the question of the cost. Evening school instruction in welding is more costly than any other kind of service. This is not so much a matter of the first cost of the equipment when compared with the cost of equipment for other lines of evening school service. It is the cost of the gas, electric current and supplies used in the instruction, a factor which has prevented many evening schools from going into this sort of instruction and which has also prevented many evening schools from giving adequate practice in welding work.

Some idea of this cost may be furnished by this statement: Our experience shows that the cost averages not less than 50 cents per student-hour for gases and materials, which means $2.00 per student for a four-hour evening class, the cost of the instructor being an addition to this expenditure. No evening school, public or private, can carry on welding without setting up a special fee to help meet the cost of the extra expenditures due to the nature of the work. The Dunwoody students pay an average of 15 cents per student-hour as a special fee as against the cost of 50 cents per student-hour plus the cost of the instructor.

Students attend four hours per night, one night per week, for a period of twenty-five weeks, a total of 100 hours per year. The actual cost to the school for this service is about $50.00 for gas and materials and about $10.00 for the instructor, a total of $60.00, not counting any overhead. For this service the student pays $10.00 plus a registration fee of $5.00, or, in other words, he puts in $15.00 and the school puts in an outlay which it would not be able to make if it were not an endowed institution. That is the purpose of the endowment.

By the customary policy of the school, instructors in welding are paid for their first year's service at the rate of $1.75 per hour and rise in a period of four years to a maximum of $2.50. This means that the present quota of instructors is being paid at the rate of $10.00 per night for their services.

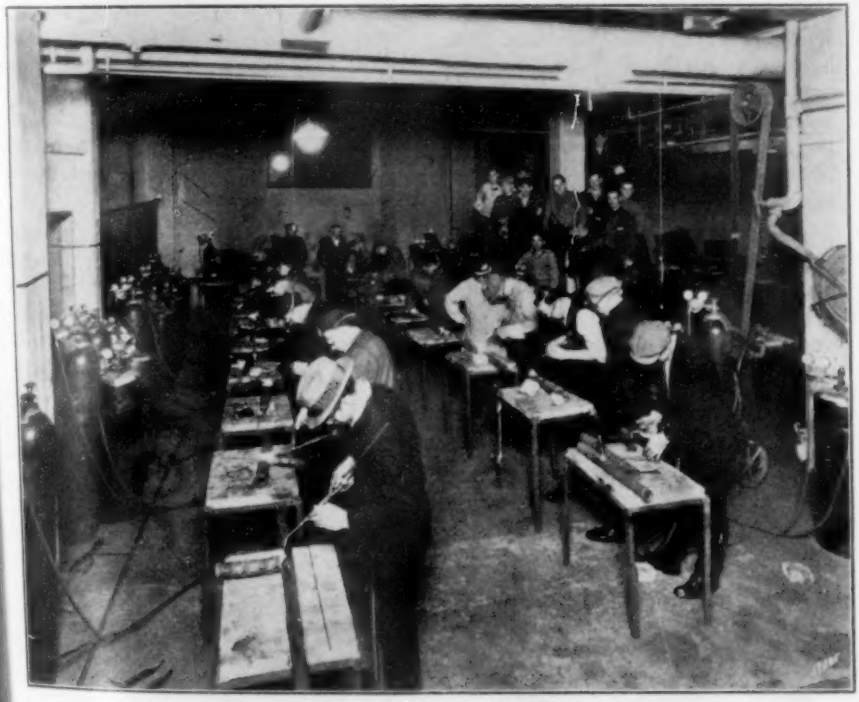
Under the foregoing conditions the school, naturally enough, has been tremendously interested in everything that would keep down the cost and yet make for efficient instruction. Among the devices that have been used the following are probably worth noting:

In the very nature of the work, it is impossible to carry on production in this course and sell the output, as is done in some of the other evening school classes. The school, therefore, has resorted to the trick of employing scrap material of all kinds in the welding work and this has served just as well as new material. Furthermore, the school has learned that lighter material serves just as well for practice by the novice as the heavier material and by using lighter material and a smaller tip, training

results can be secured just as efficiently as would be secured with a larger tip and heavier material.

This serves for a part of the course, after which the larger tip and the heavier material are brought into the training scheme. Incidentally, it should be noted also that the school is now planning to install its own acetylene generator in order to reduce the first cost of this material.

The demand for instruction in welding, particularly from those who live outside the Twin Cities and cannot attend the evening classes, has grown to the point where the school has decided to open during the next school year, beginning October 1st, a day school course. This course is designed to serve the needs of persons employed in industries where welding equipment is used, who can profit by the instruction.



STUDENT WELDERS AT WORK

During the fourteen years that have elapsed since the welding work was started, the Institute has trained more than 1400 different workmen in welding. These workmen are engaged in this work not only in the cities of Minneapolis and St. Paul but throughout the Northwest and in other parts of the country. The demand for the service is increasing every year.

Dunwoody has operated very few courses of instruction about whose value it feels more certain than about the value of the welding, and there is no service that the institution has rendered in which its officials take a greater satisfaction.

Welding in Aircraft Construction*

By Richard M. Mock†

AIRCRAFT construction has progressed so rapidly in recent years that it has been quite difficult to follow in all its details. From the almost universal use of wood structures with metal fittings we have come to structures of various high strength alloys. Among the first metallic airplane structures (Fokker, 1911) were craft with carbon steel welded tubular fuselages and wood wings, a type of design which is the most popular today. Parallel to this development has been the airplane of duralumin. Because of the fact that duralumin cannot be welded successfully, rivets are almost exclusively employed. The majority of airplanes of this type have been constructed of corrugated sheet which, in addition to being part of the structure, forms the covering. In these airplanes only the most highly stressed parts are of steel.

A type of construction which is almost standard practice in England and used by a few manufacturers in the United States, is that employing duralumin tubes with steel fittings. Here, the steel fittings are of welded construction, but because of the fact that many European countries do not permit welding in the primary structure, it is necessary that these parts be machined. The Curtis Falcon, standard observation plane of the Army Air Corps follows this type of construction with welded steel fittings for securing the duralumin tubes.

With our increased knowledge of metal airplane construction we are slowly replacing parts of wood. Wherever high stresses occur, steel seems to be the most economical material from a strength weight viewpoint. The use of steel naturally leads to welded construction. In parts where more bulk of material is needed, duralumin is more common, making for riveted construction.

Though welded fuselage structures have been standard practice for the past few years, it is the opinion that welding was retarded by the lack of knowledge of the subject on the part of the aircraft designer. Of late, numerous tests have been run by various agencies such as the Bureau of Standards, Army Air Corps and various individual manufacturers on the strength of welded structures. This increased knowledge of welding has resulted in an increased use of welded parts. Welded steel control surfaces are now almost standard on all American airplanes and though the majority of wings are still constructed of wood there is an increasing tendency toward metal, both duralumin and welded steel. Fittings of duralumin and steel are used in about equal quantities. Heat treatment facilities have

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†Aeronautical engineer, Bellanca Aircraft Corporation, New Castle, Del.

aided greatly in the use of both duralumin and steel construction and now heat treated welded parts are common practice.

The question of whether or not to use a welded structure in a certain design depends upon many factors. The size of the airplane, the service to which it is to be put, the quantities in which it is to be produced, its price class, the materials available for manufacture, as

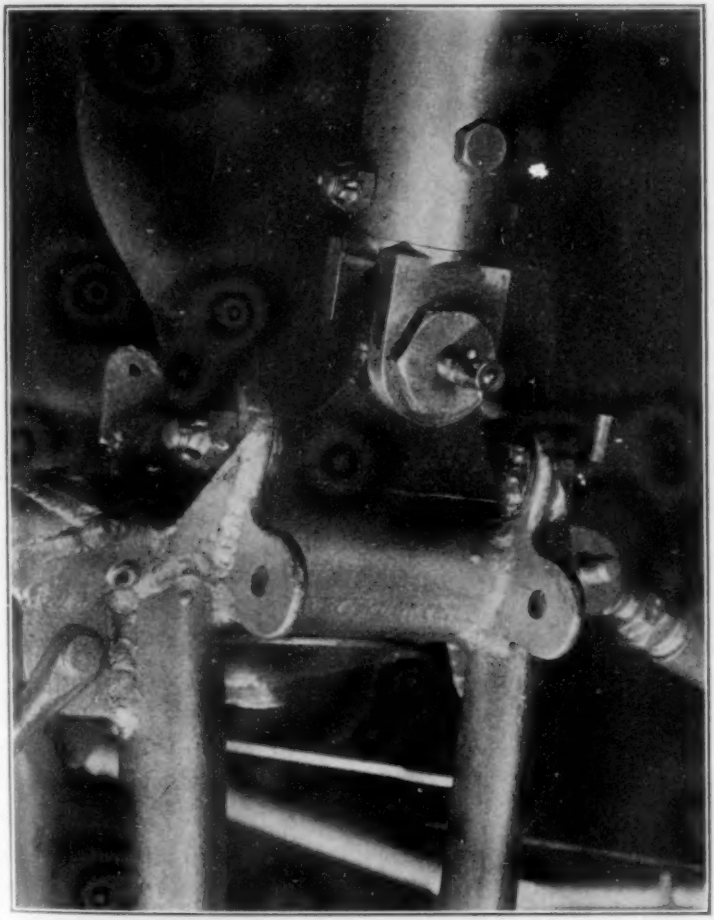

FIG. 1. LANDING GEAR FITTING AND WING HINGE FITTING, CURTISS PURSUIT PLANE. NOTE THE HOLLOW RIVET TO INSURE STRENGTH. THIS IS NOT COMMON PRACTICE

well as the trained personnel that may be secured easily. In this country it is practically standard practice to employ welded steel tubing in the fuselage structure. The usual practice is to employ round steel tubes braced in the form of a truss with the tubes meeting concentrically. Four longitudinal members give the fuselage

its rectangular cross section and these are braced by additional cross tubes or wires. At the rear of the fuselage, simple joints are employed while at the forward portion it is desirable to have the interior unobstructed, necessitating a rigid box without cross bracing. Various designs for joint welding in steel tubing have been used, but rather

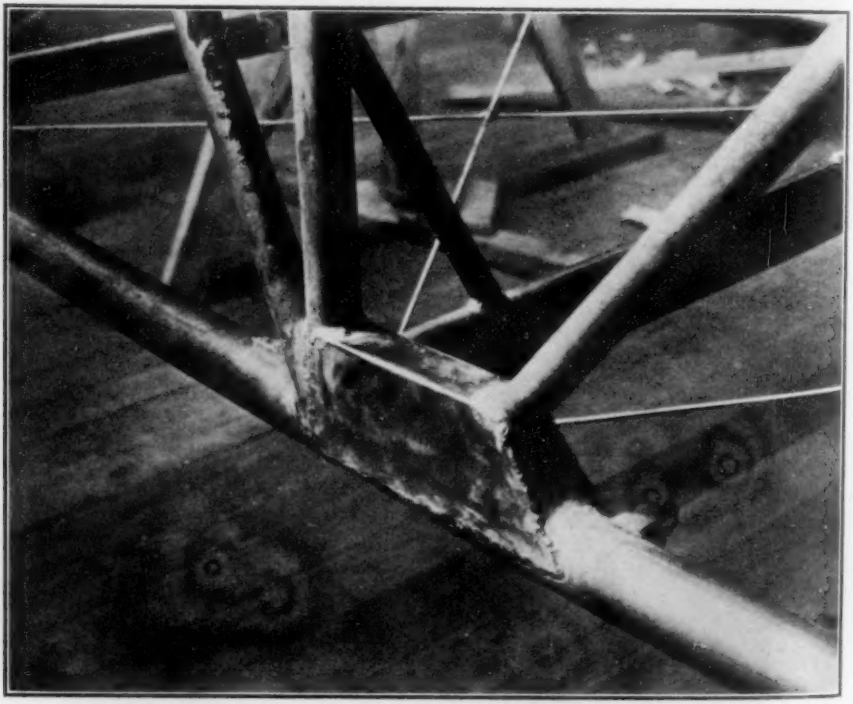

FIG. 2. FUSELAGE JOINTS SHOWING BRACING AND REINFORCEMENT. BELLANCA C. H. MONOPLANE

than state that certain types of joints are more successful than others, it has been found that if certain principles are followed the maximum strength will be developed. It is practically impossible to test every type of joint that might be used in any design. Tests on typical joints have shown that maximum strength may be obtained by taking exceptional care that the proper amount of heat is given to each of the parts welded. This may be obtained by proper arrangement of the members as well as not having too great difference in thickness of materials. It must be recalled that exceptionally light gages are used in aircraft construction, most being .035 inches or .049 inches, and sometimes running as low as .022 inches. If care is not taken, one piece of metal will be burned before the other has reached the proper temperature for fusion.

Edge welds should be avoided and provision should be made so that welds may be made away from the heavy members toward the lighter ones. When very light gage material is employed welds should be

made from one side only. In addition, care must be taken that the members will cool without causing undue internal stresses. This often causes cracking in a light gage member when it is one of a number that form a cluster of tubes, or it is welded to a much heavier member. As the tubes cool after welding, there is a certain amount of annealing adjacent to the weld. If the design of the joint is such that there is a complete circle of weld around the tube, and there is a bending stress in the member, it will undoubtedly fail in this annealed portion. A complete circle of weld usually may be eliminated by producing a "scraff" or "fish mouth" effect which in addition gives a slightly longer weld. Though this slightly increases the cost of production, the resulting increase in strength is more than compensated. Of course, in all our simple tubular columns we have a circle of weld at the ends and for this reason we never employ a coefficient of fixity of more than two when using any of the column formulæ. When members are continuous through a joint, they are calculated as two separate members meeting at the joint.

In the design of welded joints it is nearly always possible to eliminate welds in tension and place them in shear. Failures have been known when tension welds have pulled out completely by tearing in the annealed portion.

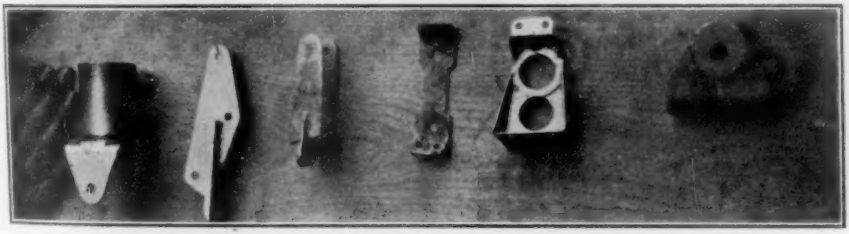

FIG. 3. TYPICAL FITTINGS OF BELLANCA C. H. MONOPLANE

It is usually customary to have all the members meet concentrically unless the eccentricity is taken into account in the design of the affected members.

Often, in our airplanes, we find it necessary to employ other than round members. To give strength in the proper direction I-beam sections, box sections and oval sections are employed. To facilitate manufacture, square section tubing is also used. Practically all of these sections are employed in the construction of a Bellanca fuselage. In addition, much of the secondary structure, such as cowl and fairing supports, control braces, pulley housings, etc., are welded to the primary structure.

Occasionally, by force of circumstances, one has to break some of the basic rules of welded joint design. In our planes we have been forced to weld a ½-in. steel lug to an 0.049-in. sheet. To do this properly, it is necessary to have two welders with two torches. The helper aids in preheating the heavy piece while the welder joins the two members. It might be well to mention at this point another "trick"

that is often resorted to. Should it be necessary to weld to one side of a tube, the tube will bend so that it is concave on the welded side. A little heat applied to the opposite side will straighten it.

Regarding the design of welded joints and trusses, one most important point must be mentioned; that is cost. One of the largest items is the labor cost. This is divided between the cost of preparing the members and that of welding them. The ends of members should be simple so that they may be prepared cheaply. Odd curves, slots, fish mouths, all tend to increase cost. In addition, the welds should not be exceptionally long. Rather than use an extremely long weld, a dif-

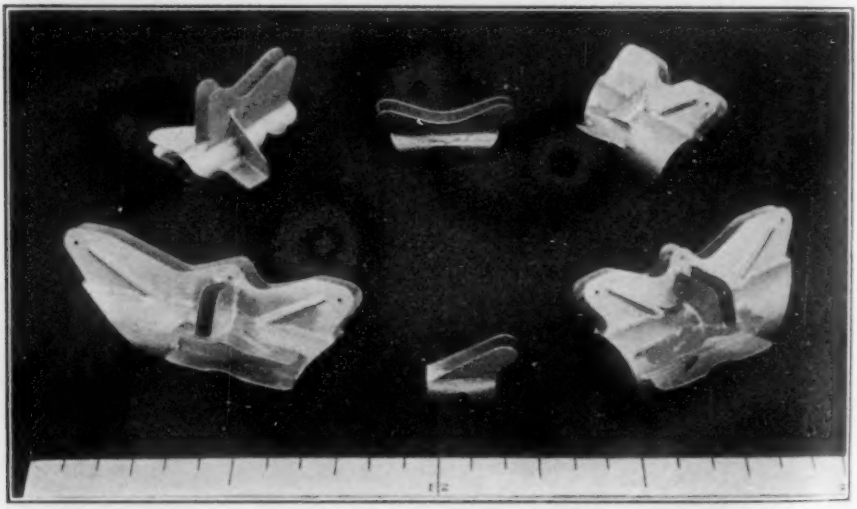

Fig. 4. Curtiss Fittings for Ends of Duralumin Tubes

ferent section member might be substituted. Provision should also be made so that the truss will fit a jig without too much complication.

Until recently practically all aircraft fittings were of welded construction. Now there is a great tendency toward forgings and high strength aluminum alloy castings. These parts are usually developed by first building up a welded fitting and later substituting the forging or casting. However, a considerable number of highly stressed parts are being welded and heat treated or normalized later. This is quite common on tension members. Often a small unit of an assembly, perhaps a part of landing gear, is heat treated and welded to the airplane afterward. This is accomplished by welding to a portion sufficiently far from the highly stressed unit heat treated that the heat of welding will not affect the heat treatment. It has been proposed, though never accomplished, to the writer's knowledge, of heat treating these assemblies while in jigs, so that they will not be distorted during heat treatment. It is believed that by careful heat treatment no undue stresses will be set up in the assembly.

For experimental purposes, welded structures seem exceptionally desirable. Elaborate jigs are unnecessary, equipment is comparatively cheap and changes may be executed with a minimum of effort. Part may be tack welded and if finally decided upon the weld is completed, if not the part may be knocked off without injury.

Airplane control surfaces of welded steel tube construction are now becoming quite common. They usually consist of one large diameter main member, with small diameter, light gage tube welded to it.

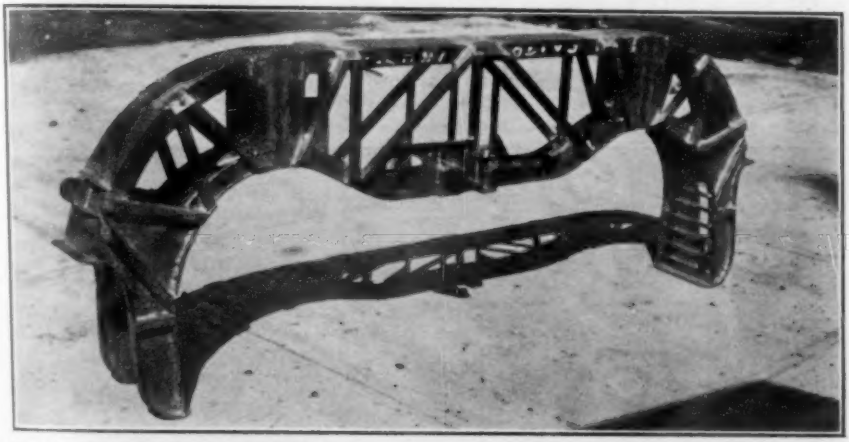

FIG. 5. WELDED LANDING GEAR BOX OF BELLANCA C. H. MONOPLANE. IT IS CONSTRUCTED OF SHEET STEEL AND SQUARE SECTION TUBING. THE MATERIAL IS CHROME MOLYBDENUM STEEL

Welded rings are being constructed with spars built up of two tubes spaced about 8 in. apart, with a Warren truss of tubing welded between them. It is understood that considerable labor is sometimes experienced in welding. This is accomplished by continual heating and hammered until the desired lines are obtained. Heat-treating furnaces are now available for heat treating spars up to 25 ft. long. Welded wing ribs are not believed desirable because of their weight and the difficulty in getting a perfect contour for the wing section.

In addition to welding in steel, a great deal of aluminum welding is done. This is especially on gasoline and oil tanks. Tanks of both aluminum and duralumin are riveted and then the seams and rivet holes welded over. Fittings for plumbing to the tanks are also welded in place. Other aluminum welding is done, to a slight extent, on cowlings and fairings.

To return to the aircraft steel, I should like to mention something about the materials used. The most common is crome molybdenum alloy of S. A. E. 4130 specification. In sheet, it is designated 4130X. Chrome molybdenum steels have certain air hardening properties, which make them highly desirable for welding. Light gage parts may often be worked in the annealed state and then welded with the rapid air cooling resulting in a certain amount of heat treatment. Occasion-

ally in parts where repeated stresses occur, such as in engine mountings, it is desirable to have more bulky material for the same strength, and here 1020 carbon steels are sometimes employed. However, chrome molybdenum steel would give a still higher strength for the same weight and there would not be the possibility of a workman mistaking carbon steel tubing for chrome molybdenum which might result in disaster. For this reason only chrome molybdenum tubing is kept in most shops. However, for fittings, which are usually built up from sheet stock, carbon steel is sometimes desirable where intricate bends are necessary and continued reheating employed. Occasionally, especially in large diameter tubes, chrome molybdenum cannot be obtained and it is necessary to resort to carbon steels with carbon content as low as 1015.

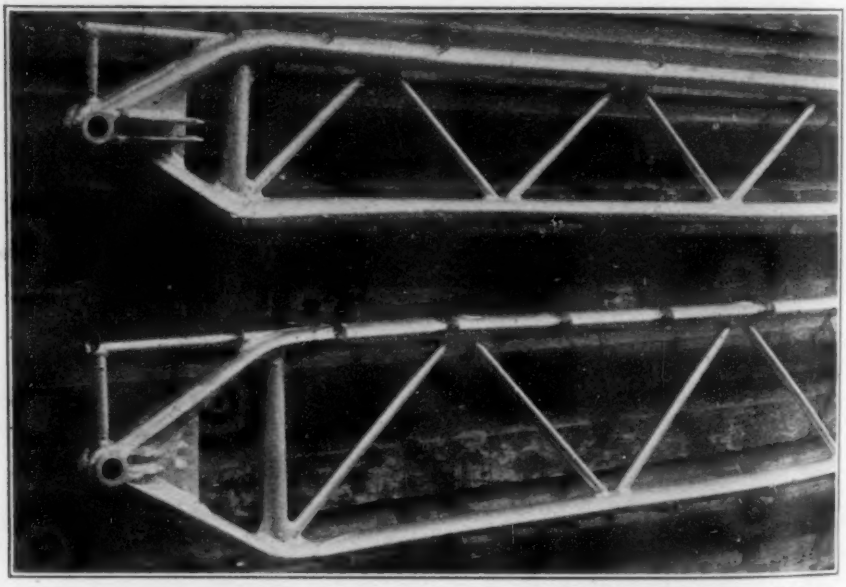

FIG. 6. CURTISS CONDOR—TWIN ENGINED BOMBER. WING SPANS OF CHROME MOLYBDENUM STEEL TUBING. NOTE USE OF OVAL SECTION MEMBERS

Nickel steel is used almost exclusively in bolts and exceptionally highly stressed members. Though welding of nickel steels is prohibited, we have found that a highly skilled welder can weld nickel steel quite successfully. However, the human element is too great and welding of nickel steel poor practice.

One other welded material that is used in limited quantities in airplanes is Stellite. Tail skid shoes receive considerable abrasion and, though of manganese steel, are usually finished with a ⅛-in. layer of Stellite, welded to the bottom.

For welding chrome molybdenum members, Swedish iron welding rod has proved the most satisfactory. When members are to be heat treated after welding, there has been a tendency toward the use of

rod of the same material as the parts to be welded in order to give a more homogeneous unit after heat treatment. We have found by actual test that an excellent joint, though somewhat more difficult to weld, can be obtained. This applies only to parts for heat treatments. Some authorities state that they have tested joints using chrome molybdenum rod and have had consistently high values and then found one member with strength about one-quarter of the rest. This might be attributed to the difficulty of welding.

As to welding equipment, because of our greater knowledge and experience in the use of gas welding, oxy-acetylene is used almost exclusively. I know of only one manufacturer employing electric arc welding. Other forms of electric welding are used to a certain extent by some of the automobile manufacturers who have taken up the manufacture of airplanes. The cost of elaborate and complicated jigs has been almost prohibitive for use in designs that are changing so rapidly and being produced in such limited quantities. Torches for aircraft welding are usually quite light and employ fairly fine tips. We have found that our men prefer a light weight torch with a good grip, about 1½ in. in diameter, eliminating fatigue in a day of welding with a light torch.

In endeavoring to avoid the problems of strength of welds, warpage, jigs, production methods, training and supervision of welders, many manufacturers are employing riveted duralumin structure. In welding duralumin it is well known that due to welding the strength is lost. The strength cannot be restored by any form of heat treatment. In riveted structures of light gage duralumin the heading of the rivets causes the metal to elongate, necessitating jigs almost as elaborate as those to prevent warpage in welded structures. There is an increased labor cost, as practically every riveter must be assisted by a header. In addition, there is again the problem of workmanship. If the holes for locating the rivets are not drilled properly a few of the rivets will carry the entire load, necessitating the use of an excessive number of rivets to prevent failure. Should the rivet holes be elongated additional complications will result.

In welding fuselages we have the great problem of warpage and truing up. It might be well to describe the methods employed in the Bellanca shops. The tubes are first cut to exact size and prepared for assembly in the fuselage jig. By preparation is meant the ends are cut and all bench welding possible is completed. The members are then placed in a heavy jig of angle irons. This jig is built to have the same shape as the fuselage so that with the tubes clamped in the corners of the angles they form the side truss panels of the fuselage. Both side panels may be welded at once. In this jig all of the outside welding is completed. The jig is mounted on bearings so that it may be easily turned over for welding the bottom. No tack welds are employed, all welds being completed. Tack welds are avoided as the warpage would have the tendency to pull the tacks, or if they were too strong, cause some harm. About 75 per cent of the welding is completed in this jig. The side trusses are then taken out and stored

temporarily. In taking the trusses out of this jig there is practically no tendency for the members to cling to the angles and no tendency to spring after being removed. The panel checks to within 1/8 in.

Using this jig, we can produce six side panels or three pairs in one eight-hour day, employing four welders and two set-up men. Heretofore, fuselage welding has been the "neck of the bottle" in aircraft production. By using more men and working shifts practically, the rate of production can be increased considerably. At Bellanca we believe we have our welding problems pretty well licked. Mr. Harold Schneider, our welding foreman, has designed both this jig, as well as our assembly jig. In addition, he is in charge of training and supervision of welders.

The fuselage assembly jig is of much lighter construction than the jig described above. It, too, is made of angles but of light gage. Unlike the primary jig, it supports the members from the outside. In it are placed two side frames, the cross members are then located and welded in place, wing hinges first and then engine mount, later working back to the tail, where the tail post is welded in place as the last operation. In this jig all welds except about 5 per cent are completed. Upon removal, the fuselage is true for length within 1/8 in., while the hinges are never more than 1/32 in. out, if at all. It must be realized that this is exceptionally accurate, considering the complication of the truss and possibilities of warpage and deflection.

After leaving this last jig, the landing gear assembly is welded in place. This consists of a box built up of sheet steel and square section tubular cross members. Then tie rods are put in place and trued up. The welds are now minutely inspected and fuselage passed on to be protected against corrosion.

A few words might be mentioned regarding our methods of training welders. We have found it cheaper and better to start a green man than to break in an experienced welder to aircraft work. The experienced man on heavier material must first unlearn his old habits. The apprentice welder spends his first few weeks on the bench welding scrap and then goes to tacking secondary structural parts, such as fairing strips, cowl supports, pulley housings, etc. He is always under the supervision of an experienced welder. After about six weeks of tacking he starts tacking fittings and parts of secondary importance. He continues for about six months when he is welding most of the primary structure, and about three months later is usually qualified for any type of welding. Welders are tested about every two weeks. It has been found that continued inspection and testing tends to make the welder more careful with his work.

How to Organize and Operate an Industrial Welding School*

R. K. RANDALL†

LIKE any other subject pertaining to general welding problems, the successful operation of a welding school offers so many variables that the laying down of any set rule is impractical. However, there are certain business and academic rules that can be applied with some degree of uniformity in making a welding school function.

We will start with the assumption that some individual or group wants to start a welding school. The picking out of a location is to be considered first. The location must be centrally located so that students can be enrolled from all sections of the city, and also that out-of-town students can get to their classes with the least amount of time being spent in transit.

In most cities there is usually a certain center that stands out as an educational section; for instance, in Cleveland, we are located in a section that supports three business colleges; also the Y. M. C. A. Schools and the Y. W. C. A. Schools and another small shop that gives machine practice. This location gives us a certain amount of what might be termed transient enrollments. In other words, men sometimes shop for education, and if they are undecided just what they want, a visit to our school, accompanied by the pyrotechnic display, sometimes makes them decide that welding is an interesting trade, and worth while taking up.

The building occupied by the school is, of course, important. The office is the first place seen by the prospective student. I have studied prospects for about eight years and I am convinced that the majority of men who investigate trade schools do so with a certain feeling of suspicion. The first step is to disarm them of this feeling and make them feel that they are among men who are really interested in them, and understand the trade about which the prospect is interested.

The sales talk that takes place during the prospect's visit may be either of the high-pressure or conservative type. I strongly recommend the conservative sales talk.

After a short talk with the prospect, we take him out to see the shop or laboratory. Our's is equipped with sixteen oxy-acetylene welding torches, also cutting equipment is set up on individual trucks. We manifold our gases, and each student gets his own correct pressure from individual line regulators. We feel that the more makes of torches the student becomes familiar with, the more confidence he has; therefore we have not standardized. We also have two 200 amp. arc welding machines.

*Paper to be presented at annual meeting, A. W. S., April, 1929.
†Cleveland Welding School, Cleveland, Ohio.

We will assume that John Doe has visited our shop, seen the school, and enrolled. What do we do with him?

We start him out with a two-hour lecture on equipment, make him set up an outfit, turn on the gases, and get a neutral flame by adjusting the cross-bars on his regulators, and show the effects of the different flames on metal. We then assign him to a torch and he starts off. It would be a long story to tell of all the steps he goes through to learn welding; suffice to say that every step is carefully planned.

Material

We pay fancy prices per pound for our scrap material that the student is given to practise on. It is a real item in the cost of training. We have sheared for us light gage metal into pieces 6 in. x 4 in. We have ⅛-in. steel cut by shears into pieces 2 ft. x 1½ in. We have our 5/16-in. steel purchased in pieces 8 in. x 12 ft. long. These we cut up into coupons with the cutting torch. Cast iron is purchased from junk yards, care being used that the pieces selected are of the "rigid" type so that expansion and contraction problems are always presented. Cast aluminum pieces are also purchased the same way. To sum up the foregoing, we believe that the material used for practise should be of shape and size to suggest "Value" rather than "Scrap."

Training and Instructors

The number of hours training necessary to give a man enough manual skill to enable him, upon the completion of the course to hold down a job, is variable. My honest opinion is that the average intelligent man can acquire enough skill to successfully hold down a job with eighty hours training, providing that the training is carefully mapped out and given under the direction of capable instructors. Notice I said "Instructors," not welders.

We have three extra night instructors and we insist that they read and keep up with the fundamentals of good teaching as outlined by leading vocational teachers. It is a hard task to pick up men who have the qualifications of welder and teacher, but careful selection from a group of applicants will usually solve this important problem.

Checking Welder's Ability

We do not hold rigidly to an eighty-hour program, however, and give extended student hours to those who need it at no extra cost. When we accept a man for training, he is accepted on a probation basis, and at the end of a few days, if we feel that the student is making no progress and does not show the initiative and mental ability necessary to become a welder, we try to discourage him. We refund to him his money with the exception of a small fee that we are entitled to for whatever little gas he may have used.

When a man starts, we pay special attention to what might be termed general interest in his work, general adaptibility, and initiative. If a man shows a reasonable amount of the three above traits, he may be considered as suitable material to develop into a welder. However, in addition to this, constant checking up of his work is necessary to see

whether he possesses that other quality of job conscientiousness, or, in other words, honesty in his work.

The breaking of welds of cast iron or steel; the breaking of aluminum welds; the breaking of brazes made on these materials is very necessary, as it does make the student perform each operation to the best of his ability and because it teaches him that appearance is secondary and that the quality of the operation is what he is graded on. I might add that with every job we have a job sheet or questionnaire, so that, in addition to the practice training received on a given operation, he must have a reasonable talking knowledge of the process. These papers are graded, and it is interesting to observe the interest that is taken in preparing the answers. We do not have any final certification tests, but insist that each man pass tests to our satisfaction after each operation is completed.

Placing the Welders

A welding school is really a manufacturing plant, only instead of turning out barrels, or automobiles, it turns out welders. In other words, for a welding school to be successful, it is necessary to know where the manufactured product, that is, the welder, can be marketed. In order to do this, constant contact must be kept with local and semi-local firms using welders. Form letters, keeping before these firms the fact that your graduates are capable men, bring results, and usually the demand on us for graduates *exceeds the supply.* The value of cooperation with employment managers cannot be over-estimated. We devote an hour a day to nothing but placement service at the office, and in addition to this, we do a great deal of other missionary work to help our students get placed.

Incidentally, a great many of the industries are hostile and would not take one of our men if they knew he was just out of school. However, these same firms, in spite of this fact, accept many of our graduates without knowing, and are satisfied with their work. Any school, however, devoting time enough to placement service can, and will, eventually overcome the existing prejudices that some firms have against welding school graduates. Incidentally, the time and effort spent among placement lines represents a real financial factor in the cost of operating a school.

Commercial Work

The question is often raised as to whether or not a welding school is justified in accepting commercial work; having students do the work. My answer to this is generally "NO." We do, however, solicit certain jobs because they have varied types of welding on them. For instance, we make paint tanks made up from a shell with a welded longitudinal seam, the top and bottom are made of cast steel; on the sides are trunions; into the trunions are welded the axles. Inside the tank we fit an agitator made up of $\frac{5}{8}$-in. round steel, $1\frac{1}{2}$ in. x $1\frac{1}{2}$ in. angle. When we have an order for these tanks, we let the advanced students do most of the work on these tanks because we feel it is a remarkable opportunity for what is known as "transfer of training," that is, applying the principles of practice to actual work. We also weld an automobile frame or a cracked cylinder block with the same thought in mind.

Jobs of this nature do, of course, add to the income of the school, but

our experience has been that in order to have students do commercial work, the supervision necessary to carry out this program adds to the general over-head so much that it is not profitable.

The training every student receives must be so thorough that he goes out as a "booster," not a "knocker." Our experience is that every student who goes away satisfied will eventually send in another prospect. Forty-five per cent of our present enrollment is with us due to the recommendation of former students.

We sell the Oxy-acetylene welding course as one unit, and the Electric Arc welding course as another unit. Invariably, a man only signs up for one of these units, but it is interesting to note that eventually he comes back for the other course.

Interest in Students

Last, but not least, a welding school can only be successfully operated by men who are willing to feel an interest in their fellowman. The good they can do him by giving him proper training must be, in some measure, a compensation for the time and effort spent. Those in charge should be of the type to get a thrill from the fact that Bill Jones, Tom Smith, or any other student that they train, is being helped to a higher plane of living, that the man becomes a greater asset to the community, due to his increased wages, that the man is perhaps taken out of monotonous factory production environment, or dull office routine, and placed in a trade that has a future, a trade that is interesting work, and a trade that is truly fascinating.

How to Organize and Operate an Industrial Welding School*

F. E. Rogers†

IF the title were put in the form of a question the answer or answers would depend on what kind of an industrial welding school was meant. As we see it, there are five outstanding types of schools for industrial welding training, as follows:

1. The vocational school run by a city in connection with the city school system, in which welding instruction is given.

2. The privately operated school that trains men for various trades, including welding, for a fee.

3. Trade union schools run by local unions for the instruction of their members in welding so that they can qualify for pipe welding, and other welding and cutting operations met in the construction of buildings, and so forth.

4. The school, operated by a company or corporation selling welding equipment, to train men of the executive type for their customers that

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†Publicity manager, Air Reduction Sales Co., New York.

need foremen and supervisors who can intelligently direct welding operations.

5. The school operated by a company or corporation to train men in welding for its own employment.

Organization of a school comprehends the selection of an instructor, arrangement of a training course, fitting out a welding workroom and selection of applicants for training. The welding equipment required depends upon whether the school is to train in the oxyacetylene or electric arc processes, or both. The following pertains to oxyacetylene welding training, but certain general principles up to a point apply to both processes.

The matters of selection and fitness of applicants are to large extent automatically taken care of in schools Nos. 1, 2 and 3, because men enter these schools as a rule of their own volition, and at their own expense. If they find they are not interested in welding work or feel they have not the bent for it they are likely to drop out before finishing.

This governs to some extent the operation of vocational welding schools. The action of the Common Council, the Board of Aldermen or whoever controls the city school system depends to large degree on the public attitude to any special course. If a trial class, supported perhaps by subscription, attracts sufficient members to fill, and the members continue to attend and display interest, the natural conclusion is that they see a future in welding, and are minded to give up the time and energy necessary to acquire proficiency in the trade. The vocational school in welding may then be continued at city expense on the theory that there is real interest in welding and real need for welders.

Also the privately operated school No. 2 that trains men for a fee does not need to consider personal fitness except that it would be poor business to take on a man who would simply be wasting time and money. The applicants as a rule will have carefully considered the matter before paying their money. Having paid in they are likely to get all they can out of the course, and make themselves as proficient as possible. Some may find that they have made a mistake, but the probability is that most of the class will make good and apply what they have learned.

Trade union members who take up welding are generally men who have sensed the need of learning welding because they have run into situations where the ability would have been useful and very desirable. Having already demonstrated mechanical ability they are quite likely to learn welding quickly and to acquire a fairly good grasp of principles, provided the instructor is a real honest-to-goodness teacher fitted for his job.

The welding school operated by a company selling welding equipment to train men of the executive type for their customers will be filled by men sent by their respective concerns for training. In this case the men are selected for the school by the respective concerns, and the problem of determining fitness is not up to the school director. Personal welding proficiency is not so important an end as that of recognizing proficiency or lack of it, and acquiring welding vision.

The school run by a company or corporation needing more welders must carefully select applicants as well as train them in welding practice. Many applicants are likely to feel they have nothing to lose by taking the welding course because they would be paid for their time while learning, and if they do not like welding they are at liberty to turn to something else. In other words, the company takes all the risk.

It is then up to the personnel director, or the one in charge of welding instruction, to determine beforehand as far as possible whether an applicant is by nature, inclination, previous training and general characteristics likely to make a good welder. Selection of applicants for instruction in welding for a company's employment should, of course, be along the company's policy as to employment in general, and particularly with reference to age, health, physical condition, eyesight, mechanical skill, moral qualities, previous experience, intelligence, education and executive ability.

Age: As a rule, the age limits for a life job should be between 18 and 35. Mechanics, steamfitters, plumbers and intelligent iron workers up to 40 may be favorably considered, other factors being favorable because of previous experience and skill in using tools.

Health: Of course, only men in good health, with all faculties normal, should be eligible.

Physical Condition: Although health and physical condition are ordinarily considered as the same they are not necessarily so as regards selection for welding training. The loss of a foot or the leg below the knee, or a stiff knee joint does not necessarily prevent a man from becoming a good welder. Other physical disabilities might be mentioned that could be ignored in considering an applicant who otherwise would qualify.

Eyesight: Eyesight also is part of physical condition, but it is one requiring special investigation. A welder must have good eyes and normal vision. He must be able to see through colored lenses and see oxide formations and unequal heating in a temperature of 3000 degrees F. or more and to interpret what he sees.

Mechanical Skill: By this we mean the applicant should have some natural aptitude for handling tools and apparatus.

Moral Qualities: Under this head should be habits of industry, honesty and ability to work with others. Honesty is highly important because a man without well-developed moral sense will not as a rule be a dependable welder.

Previous Training: Men who have learned a trade and worked at it are likely to be good welders if they have been successful in their previous occupation and provided that they are genuinely interested in welding.

Intelligence: By intelligence we mean the ability to understand directions and to carry them out; also the ability to learn and to understand new principles.

Education: A welder should have had a common school education—be able to read, write, and make ordinary arithmetical computations.

Executive Ability: This is or is not important, depending on what the

applicant's future position is to be. However, it is always desirable in men who are being trained at company expense, and is a factor to be carefully considered from a managerial viewpoint. Some unpromising material for welders may turn out to be valuable in an executive way because of ability to command respect and to direct the work of others.

Welding School Workroom: Quarters to be set apart and equipment to be provided for a welding school depend of course on whether the school is to be temporary or permanent. The following suggests facilities desirable for a permanent school: a small lecture room furnished with table, chairs, blackboard and charts of apparatus; also welding apparatus sectioned to show construction and how it functions.

The work shop should be fitted out with welding outfits, one or more cutting torches, welding tables, work bench with two substantial vises, grinder, hammers, chisels, wrenches, pliers, files, and so forth. A tensile testing machine of 50,000 pounds capacity is desirable but not absolutely necessary.

Although an oxygen manifold and an acetylene generator with distributing pipe lines to the welding stations would be more in harmony with an up-to-date industrial installation, they will not be included here because the average welder is more likely to work with portable outfits. Therefore, he should become thoroughly familiar with this type of welding and cutting apparatus. If at some time in the future he should obtain employment in a welding shop having pipe line distribution it will be an easy matter to adapt himself to the new conditions.

Adjacent to the workroom should be a wash room and toilets, and lockers should be provided for each member of the class. Space must also be available for oxygen and acetylene cylinders, filled and empty. Overalls, gloves and goggles should also be provided in order to insure that each member be properly clothed for welding.

Instruction: Although the instructor must be a teacher and have ability to lecture and to talk to a class in terms they understand, he should also be very practical and have a common sense view of his subject. Instruction along the line of mostly welding and little theory will as a rule give the best satisfaction. A class should be limited to ten for one instructor, each member being assigned a welding station and outfit.

First, the class is shown the apparatus and the instructor illustrates how it should be assembled and put into operation. He will stress the proper sequence of operations in setting up, turning on the gases, lighting the torch with the sparklighter and shutting down. The class will then be required to take their equipment to their respective station and set up for welding following the sequence employed by the instructor. The first period devoted to setting up, turning on the gases, lighting the torch and shutting down, removing the regulators and hose and stowing away, accompanied by a talk by the instructor on the importance of always following instructions and what may happen if they are ignored puts the class at ease. They become familiar with the feel of the torch, manipulating the pressure regulators and needle valves, lighting and extinguishing the flames. Each member should be assigned an outfit and be required to stow it in his own locker when not in use.

Welding, rest and lecture or discussion periods should follow one after another in a schedule planned to fit the morning and afternoon sessions. The periods should be short in order to maintain interest and to accustom the men to welding without becoming unduly fatigued. Welding exercise at first is very tiring to the inexperienced man because of the dress, goggles, unfamiliar apparatus and close attention necessary.

The following schedule suggested for the school periods runs from 9 A. M. to 4 P. M. Although it does not fit the working hours of an industrial plant it can be used as a basis for apportioning the time assigned to instruction.

9:00	to	9:15	Assembly, roll call, announcements and setting up apparatus.
9:15	to	10:15	Welding exercises.
10:15	to	10:30	Rest period.
10:30	to	11:00	Lecture.
11:00	to	12:00	Welding exercises.
12:00	to	1:00	Lunch
1:00	to	1:15	Assembly and discussion.
1:15	to	2:15	Welding exercises.
2:15	to	2:30	Rest period.
2:30	to	2:45	Questions and answers.
2:45	to	3:45	Welding exercises.
3:45	to	4:00	Shutting down, stowing apparatus, cleaning welding tables, replacing empty cylinders, etc.

Progress will be faster and more will be learned by following a liberal schedule than if the welding periods are unduly prolonged. Division of instruction and the regular occupation can perhaps be best made by devoting only one-half day to the school, in which case welding instruction should be in the forenoon.

Evening Classes: Evening classes in vocational, trade and industrial schools as a rule are run on a more intensive schedule because of the limited time available. The time period of from two to two and one-half hours is devoted chiefly to welding exercises. The instructor may give a short talk at assembly, and hold an informal question and answer period during a brief rest period. The attitude toward theory and technical information should largely be governed by the class average of men attending.

Testing Welds: Each student welder tests his own welds by breaking them in a vise. At first the instructor must point out the defects and the causes. Then each one should be required to find weld defects, show them to the instructor and tell him what caused them. "Confession is good for the soul," and when a learner gets into the way of frankly criticizing his own work, pointing out the defects and telling why they appear he is on the high road to improvement. Testing welds may be varied by polishing, etching and examining the grain structure through the microscope; also by pulling apart if a testing machine is available.

The theory of successful welding instruction in brief is to select the right types of men, train them to be orderly and systematic, teach them sound welding principles, require every weld to be broken and examined for defects, and to build up self respect and confidence.

Training Welders*

L. S. THURSTON†

IT was not until after the World War had commenced in 1914 that the possibilities and value of welding were appreciated or utilized to any great extent. And even then the process, either gas or electric, was used more for repairs than for fabrication. It became at once apparent that there was need for men trained in the art of welding and to meet that demand schools were established in a few parts of the country where the process was practically taught. The theoretical study of conditions met in welding various materials as well as of the various processes was, however, largely neglected in such schools.

The wonderful possibilities of welding were soon recognized and sales of equipment showed a rapid growth until about the first of the year 1921, when they began to decline for two reasons: First, a business depression and, second, a lack of confidence on the part of the public. It is in connection with the latter feature that this paper is written.

While the schools during their early days were rather rudely equipped, they nevertheless succeeded in turning out many skillful welders, relatively few, however, compared to the number who undertook welding jobs and posed as welders. The latter class naturally soon lost the confidence of their employers, not only in their ability to weld but in the process itself and it was not until several years later that this prejudice began to be overcome. A typical curve of sales of welding equipment (Fig. 1) clearly illustrates this condition.

About the year 1924 welding began to be appreciated as a process for fabrication as well as for repairs and again the necessity for well-trained, conscientious welders became apparent. Men who had pretended to be, or thought they were welders, as well as those who wanted to be, realized this condition. So did the schools.

In the arc welding school, established many years ago by the General Electric Company in its Schenectady works, nearly 1000 men have received practical training. The course has been gradually expanded until it now covers all forms of arc-welded joints—butt, lap, edge and corner, including flat or horizontal, vertical and overhead. In addition, the course includes two weeks' practice with the automatic arc welding machine and, where students have become sufficiently adept, two weeks' practice in fabricating various pieces of equipment. This latter part of the course is of great assistance in developing the student's confidence.

The school is equipped with a number of individual welding booths, each furnished with a current controlling resistor by means of which the student may obtain the desired welding current. Each booth also

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†Industrial Department, General Electric Co., Schenectady, N. Y.

contains an iron-topped bench upon which the welding is done, a stool, a receptacle for spare electrodes and a suitable length welding lead with electrode-holder attached. Power is supplied from 60 volt, constant potential, multiple-operator generators and there is no interference of one operator by another. (See Fig. 2.)

The course in hand-welding comprises 40 lessons, each requiring an average of one day to complete by an ordinarily intelligent man. A competent instructor with an assistant is constantly in attendance, and no student is passed on to the next lesson until he has completed his

FIG. 1

previous ones to the satisfaction of the instructor. To assist the student, the instructor carefully examines his work and explains when necessary his faults and how to correct them. Experience has proved that men under 30 years of age make the best welders, as their muscles being more supple, enable them to better control the arc length—and they also learn more quickly.

Students are graded in accordance with their ability, grade A being classed as "good and rapid"; grade B as "good but slow"; and grade C as "poor." The first two are given a certificate of proficiency upon leaving. A student who after the first two weeks displays inability or unwillingness to learn, is given notice that if he does not show marked improvement in another week he will be dropped from the school. By this means only good welders are "graduated," as the requirements are high.

There should be an established uniform method of teaching and grading welders and of furnishing them with a diploma or credential which would be universally recognized by employers. The standards of such training courses should be set as high as existing knowledge of the art permits and only those men who are able to attain a proficiency of over

FIG. 2. OPERATOR IN CORRECT WELDING POSITION IN ARC WELDING SCHOOL

80 per cent should be classed as skilled welders and given diplomas. As a suggestion for such standards the writer would recommend something like the following:

Qualifications	*Standard*
1. Personal habits	5
2. Reliability	35
3. Ability to learn	10
4. Quality of work	40
5. Rapidity of work	10
Perfection	100

Under the above scheme a Class A welder should attain at least 90 per cent, and a Class B welder 80 per cent of "Perfection." No welder should be graded 100 per cent. Item I and 2 would have to be left largely to the opinion of the instructor or examiner. The remaining three items could be fixed by establishing definite standards. For example, "Ability to learn" could be defined as the time required to successfully complete an established number and kind of practical welding lessons or "samples"; "Quality of work" could be fixed as a ratio of strength and quality of weld to that of the material which had been welded; and "Rapidity of work" could be based on a time standard for making a specified kind of joint in a given material, using a definite heat and electrode if any. Some of these qualifications, such as Number 5 and possibly Number 3 might have to be changed in value as the art progresses.

Where practical training only is carried on and men take up the work at any time, it is difficult to coordinate any lecture course or class covering the theoretical part of welding. Educational institutions should do far more than they do now to establish courses and teach their students the fundamental theories of the various welding processes, the metallurgical problems involved, and the different types of equipment used.

A simple form or method of making such tests should be created and standardized for use by employers, so that they could readily check the work of their employees.

If some such program as above outlined were adopted and recognized and if all schools would set and maintain a high standard of instruction and give certificates of proficiency only to those who met such standards, there would be little cause on the part of employers or the public to doubt that welding is a safe fabricating process. Moreover, the use of welding would increase to far greater extent than at present.

DISCUSSION OF PAPERS

Written discussion of all the papers to be presented at the Annual Meeting is particularly invited. Members of the Society who will be unable to attend are urged to send in their discussions.

Strength of Butt Welds*

G. Lobo, Jr.†

I. Introduction

It is reasonable to assume that a weld made under certain conditions is better than that made under other conditions, and that the "perfect" weld will be obtained only when all conditions are right. Another way of saying the same thing is that if any one condition is not made correct then the weld can not be perfect. There are a great many variables which enter into the making of a weld, and we are endeavoring to isolate each one and to determine when each is right, so that by combining the correct conditions for each variable a "perfect" weld will be the result.

This paper covers the results obtained in a preliminary investigation and an investigation of three of the variables affecting the strength of a butt weld made with the metallic arc.

An examination of the variables which may affect the strength or quality of a butt weld shows that they are fifteen in number, which may be classified as follows:

1. Parent Metal.
   a. Chemical composition.
   b. Metallurgical conditions.
   c. Thickness.
2. Electrode.
   a. Chemical composition.
   b. Metallurgical conditions.
   c. Flux used (or bare).
   d. Size of wire.
3. Preparation of Joint.
   a. Scarf angle.
   b. Free distance.
   c. Single V or double V.
   d. Method of weld deposition.
   e. Cleaning.
4. Workmanship.
   a. Current density.
   b. Length of arc.
   c. Manipulation of arc.

Before attempting to study the effect of these variables, it was felt necessary to develop a test specimen such that the results obtained would be consistent and would give the information desired from the tests. In order to do this the following requisites for a welded test piece were drawn up, and the results obtained from tests on various shapes were examined to see how they fulfilled the requisites.

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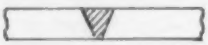
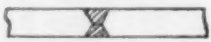
† Research Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Table I

Notched Tensile Test Piece

case	weld section	bevel	ult. strength #/in.
1		0°	43.200
2		27.8°	50,800
3		27.8°	46,400
4		17.8°	44,200
5		23.7°	47,900
6		29.2°	50,500

Note:- Each value is the average of two tests.

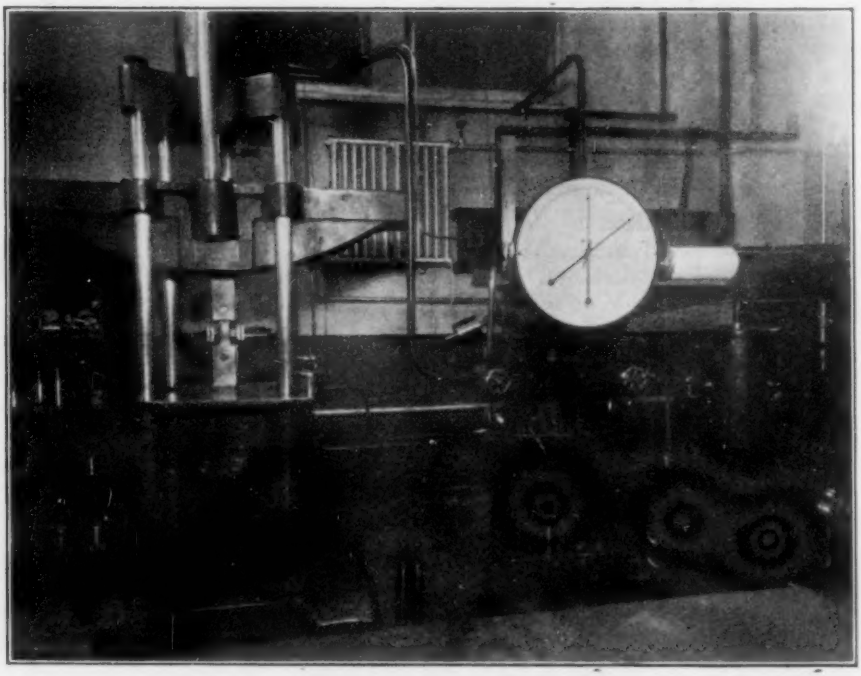


Fig. 1. Amsler Hydraulic Testing Machine

1. Uniform stress distribution at the minimum section.
2. Elimination of stress concentration or mass effects.
3. Failure of specimen should occur at the weld.
4. Maintenance of proper cross-section of weld.

For the majority of the tensile tests an Amsler Hydraulic Testing Machine shown on Fig. 1 of 100,000 lbs. capacity was used although for some of the preliminary tests a similar machine of 20,000 lbs. capacity was employed. For the fatigue tests machines of a modified Farmer type shown in Fig. 2 were used, employing a rotating beam test piece.

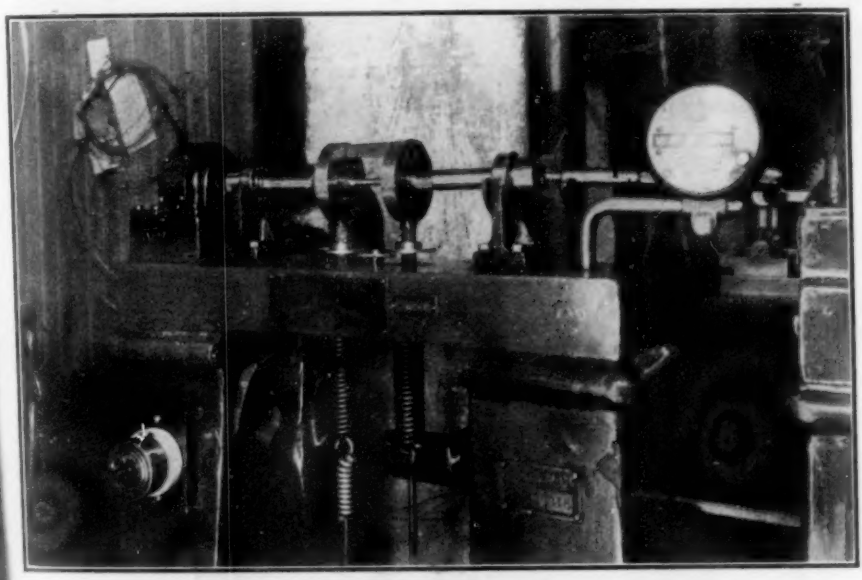


FIG. 2. FATIGUE TESTING MACHINE

The extension (except on the standard tensile test pieces, where a Ewing Extensometer was used) on the test pieces was measured by means of Huggenberger Tensometers, shown in Fig. 3. These instruments multiply the extension 1200 times, so that one scale division on the instrument is equivalent to an extension of .000033 inches of the specimen. This corresponds roughly to 1200 lbs./sq. in. per scale division, with tenths of a scale division easily estimated.

II. Selection of Test Piece.

The first type of test specimen tried had a shape as given in Fig. 4. These were all made with half-inch plate, with varying bevels and scarf angles. This shape of test piece was found very unsatisfactory since the stress distribution at the weld section was far from uniform and the sharp corners introduced other factors which rendered the results unreliable. Although Huggenberger Tensometers were used, no elastic properties could be determined, since they varied greatly, depending on the position of the instruments on the test piece. In general, the strains

were larger near the ends than in the center, so that the values of stress found will be too low.

A test piece with rectangular cross-section (Fig. 5) was tried next. Two pieces with a cross-section 1 in. x ½ in. and a 45 deg. single V and eight pieces 3 x ½ and a 30 deg. single V were tested.

Both sizes showed effects of non-uniform loading, as shown by the presence of some bending at the weld section. In the smaller piece this was not bad, and probably did not affect the ultimate strength to any great extent. In the 3 in. weld pieces, however, this bending was quite large, causing the specimen to tear rather than fracture.

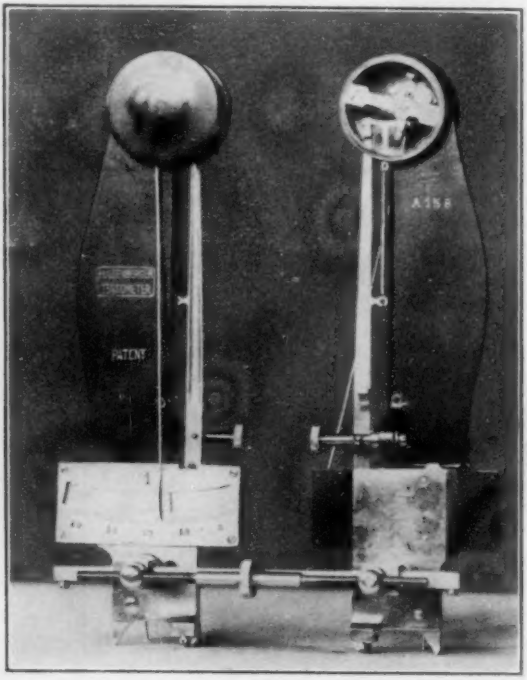


FIG. 3. HUGGENBERGER TENSOMETERS

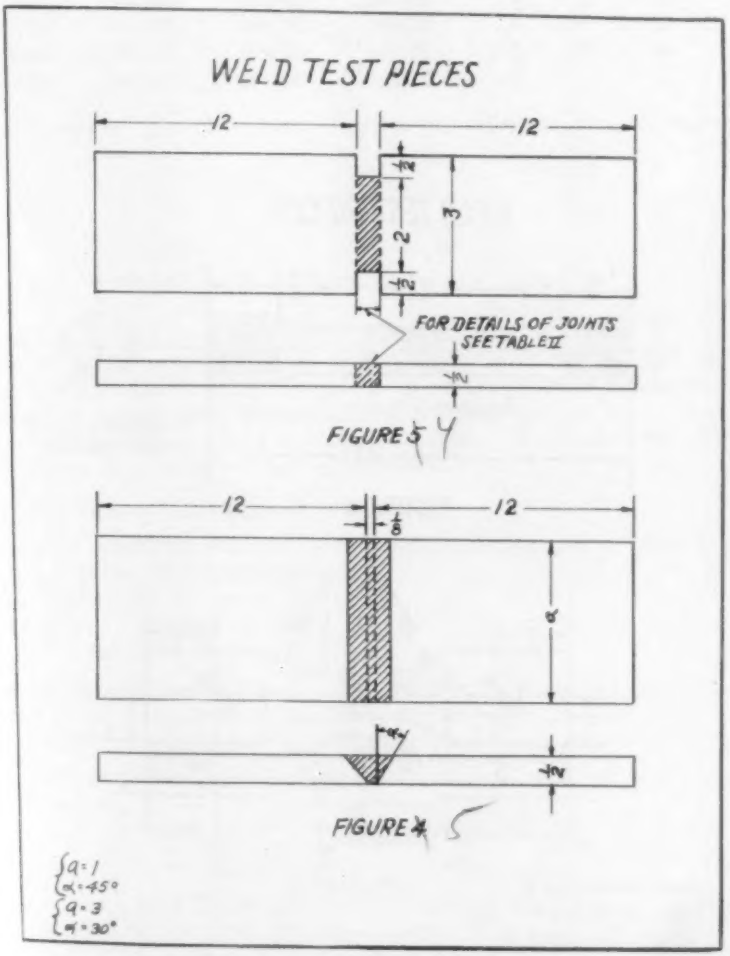
In order to remove the bending, standard tensile test pieces (Fig. 6) were then machined from the welded joints in a ⅞ in. plate. Since the grips for these specimens have lubricated spherical seats, the bending can be almost entirely eliminated. These tests gave good results, but were unsatisfactory in two respects. When the weld was a good one failure did not occur in the weld, and in addition, the fact that a round specimen was machined from a rectangular plate may or may not have had some effect on the strength.

Although these tests were only intended as preliminary tests, the results are of some interest and so they are given in Tables I, II and III.

Table II

Rectangular Tensile Test Piece

Section	Bevel	Prop. Limit, Lb./Sq. In.	Ult. Stress, Lb./In.	Modulus E, Lb./In.	El. in 1", Per Cent	Red. of Area, Per Cent
1 x 1/2	45° V.	21,600	56,100	24.0		3.3
3 x 1/2	30° V.		47,700		12.3	



As a result of the preceding tests the specimen shown in Fig. 7 was adopted. With this piece the rectangular section is maintained, the large radii remove stress concentration and failure will in general occur in the weld, since it has the minimum section. In addition, the use of a pin for loading allows the use of spherical seats, removing most of the objectionable bending. Also, movement about the pins enables axial loading to be easily attained. This is the specimen that was used in the

Table III

Standard Tensile Test Piece

Case	Weld	No. Broke Outside of Weld	Prop. Limit, Lb./Sq. In.	Yield Point, Lb./Sq. In.	Ult. Stress, Lb./Sq. In.	Modulus E, Lb./Sq. In.
1	0°	0	12,300	28,000	23,900	22.6 x 10^6
2	30° V	1	23,700	30,200	49,100	29.0 x 10^6
3	30° X*	0	16,200	27,000	28,700	24.6 x 10^6
4	45° V	4	23,800	35,900	56,200	28.0 x 10^6
5	45° X	2	27,200	32,400	52,300	29.2 x 10^6

*Through an error, the welds did not have any free distance between the welded plates.

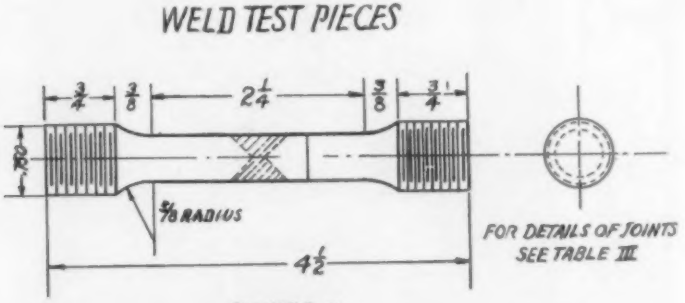


FIGURE 6

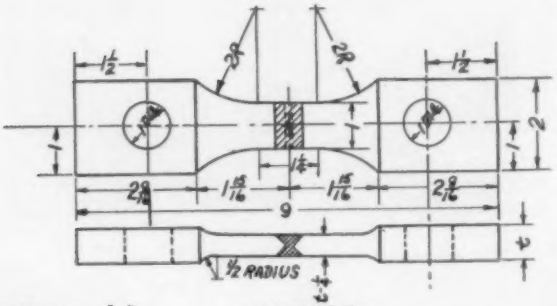


FIGURE 7

study of the variables. That this test piece effectively prevents any bending at the weld is shown in Fig. 8 and Table IV. Table IV gives the strain readings for right and left extensometers for tests on two types of test pieces, one the final specimen shown in Fig. 7 and the other the straight piece shown in Fig. 5. Fig. 8 shows the curves plotted from Table IV.

Table IV

Uniform Loading of Test Specimens

Stress, Lb./Sq. In.	Test Piece as per Fig. 7, Strain In./In. Left	Right	Test piece as per Fig. 5, Strain In./In. Left	Right
2000	.000000	.000000	.000000	.000000
4	035	035	022	050
6	073	073	050	094
8	106	104	076	144
10000	143	139	098	188
12	181	181	126	232
14	216	214	154	272
16	250	247	182	312
18	287	285	214	350
20000	325	321	250	386
22	354	352	280	422
24	391	389	314	458
26	427	425	360	504
28	458	458	406	550
30000	523	515	466	610
33	890	723	560	704
34	.001388	.001182	664	808
35000			.000786	.000930

There was no choice in the selection of a fatigue test piece. A rotating test specimen was necessary since only rotative machines for determining the endurance limit were available. This necessitates a violation of the requisite for a good test piece that the original section be maintained, but the remaining requisites are all fully met. The specimens used are shown in Fig. 9, the pieces being machined from ½ in. plates.

III. Preparation of Test Specimen

The three variables studied in this investigation were: (numbers in parenthesis refer to list of variables).

1. Thickness of plate (1-c).
2. Scarf angle (3-c).
3. Single V or double V (3-c).

This means, of course, that the other twelve variables given in the list were to be kept as constant as possible. The methods and values chosen for the constants are stated in the succeeding paragraphs.

The steel used for the tests was a low carbon steel of the following composition (1-a):

C	Mn	S	P	Si
.15	.54	.019	.026	.013

The steel was used in the hot-rolled condition as received (1-b). The electrodes used in welding the specimens were cold-rolled (2-b) low carbon steel of the following composition (2-a):

C	Mn	S	P	Si
.17	.48	.022	.031	.056

The electrodes were bare (2-c) and a 5/32 in. diameter was used throughout (2-d).

The free distance was maintained at ⅛ in. for a beveled joint, and was equal to the thickness for non-beveled joints (3-b). The method

of weld deposition was the layer method (3-d). A single bead was first run the lengths of the plate, and additional beads were added until the weld was completed. All edges to be welded were machined before welding. Thus they were clean of rust and scale, and no further cleaning was attempted before welding. After each bead was deposited a stiff wire brush was used to clean the bead before the next layer was laid down (3-e).

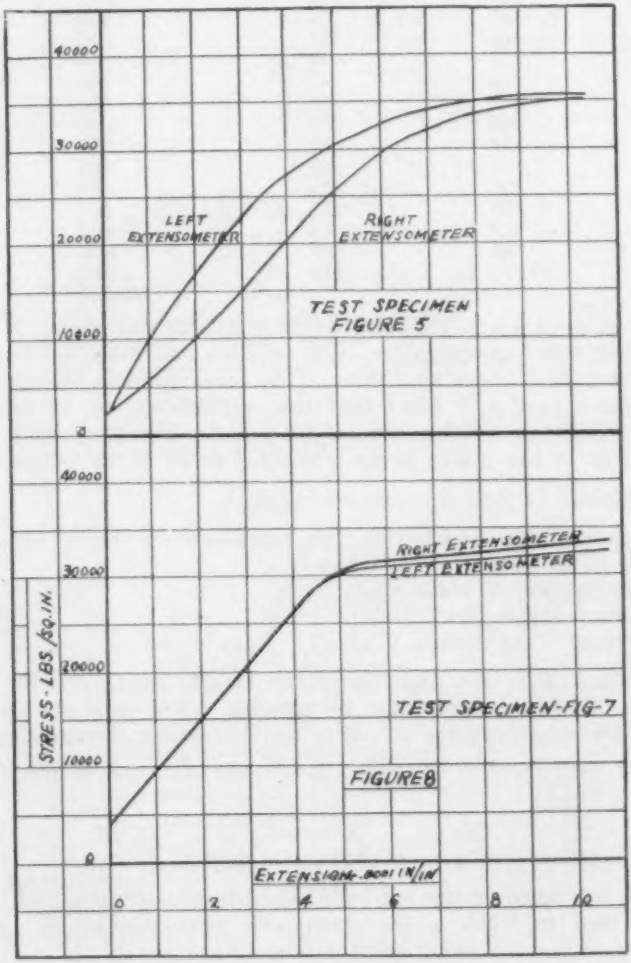


FIG. 8

In controlling the workmanship the welder was given orders to use standard current densities (4-a), which vary for different thicknesses of plate. He was also told to keep the arc not longer than ⅛ in., or a voltage drop across the arc of 15 to 18 volts (4-b) and to do the best work he could (4-c). Since these factors are the hardest to control, the

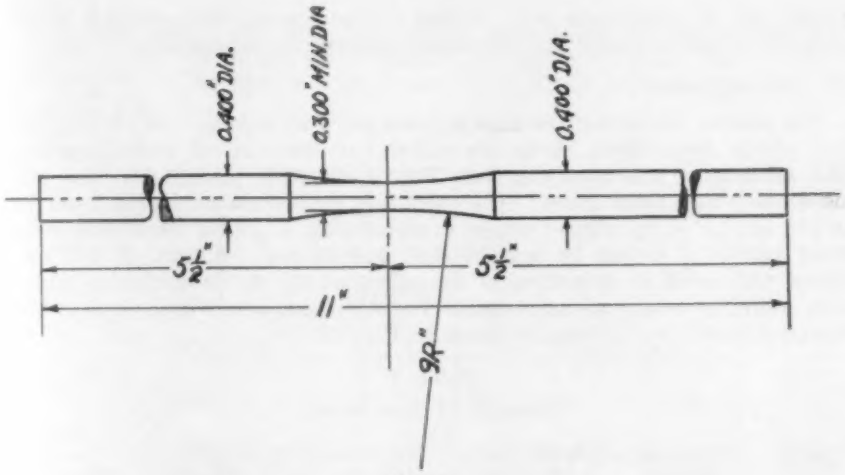


FIG. 9

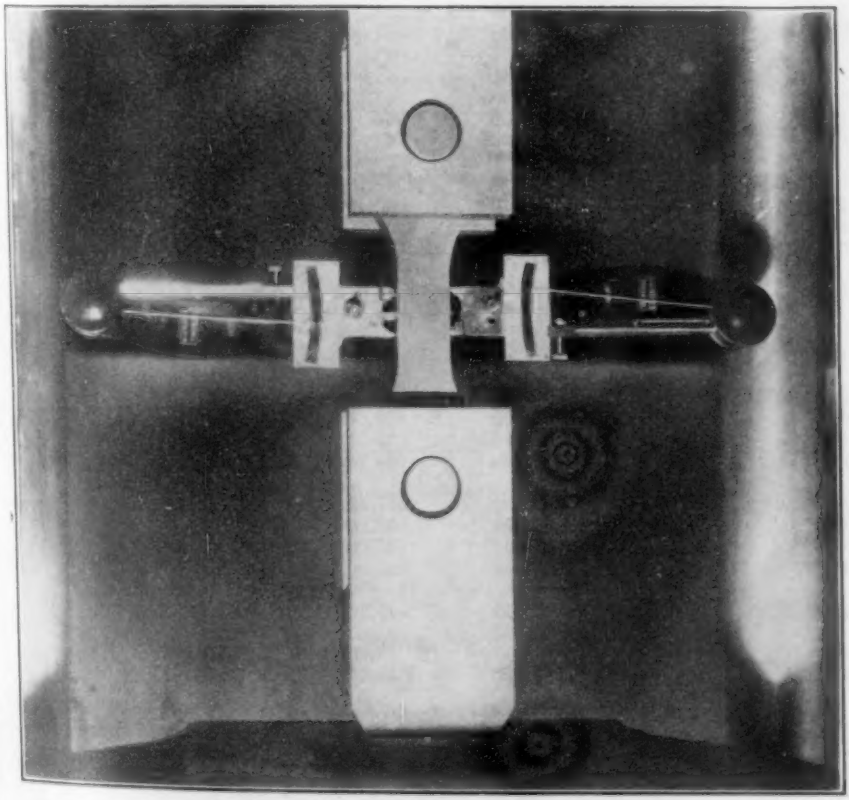


FIG. 10. TEST PIECE OF MACHINE READY FOR TESTING

entire set of specimens was welded by one man, this method being adopted as most suitable for obtaining uniform workmanship.

IV. *Test Results*

The welded plates for the tensile tests were 9 in. long. In cutting the test pieces from them, ⅜ in. on either end was cut off and discarded. The remainder was then cut into four 2 in. wide pieces, and the test piece machined from these. The thickness of the plates varied from ½ to 1¼ in. by ¼ in. steps; single V and double V joints were used with scarf angles of 0 deg. 15 deg. 30 deg. and 45 deg. A total of 112 test pieces was used in determining the effect of the three variables under test, with the results given in Table V. A picture of the test piece in the machine ready for testing is shown in Fig. 10.

Table V

Strength of Butt Welds

Type of Weld	Prop. Lt. Lb./In.^{2}	Yield Point, Lb. 1/In.^{2}	Ult. Stress, Lb./In.^{2}	Modulus E, Lb./In.^{2}	Broke Outside Weld No.
1/2″ 0°	20,300	32,300	35,400	23.5 x 10^6	0
3/4″	24,900	37,000	42,800	23.5	0
1″	29,800	36,000	43,100	25.4	0
1¼″	31,500	48,400	53,500	26.0	1
1/2″ 15° V	20,700	32,100	38,900	27.9 x 10^6	0
3/4″	20,300	32,400	40,100	28.5	0
1″	20,700	30,000	40,100	26.1	0
1¼″	17,900	37,700	42,900	22.2	0
1/2″ 30° V	24,700	34,200	47,100	29.5 x 10^6	1
3/4″	25,900	35,600	52,100	27.8	0
1″	27,500	35,400	47,600	27.3	2
1¼″	27,800	43,000	54,300	27.0	0
1/2″ 45° V	24,000	35,600	54,000	33.2 x 10^6	2
3/4″	28,300	37,900	54,000	27.3	4
1″	33,000	42,500	50,400	26.5	2
1¼″	28,500	51,300	56,500	27.2	3
1/2″ 15° X	19,200	31,100	35,400	28.3 x 10^6	0
3/4″	17,600	31,100	36,600	22.1	0
1″	16,400	30,000	39,300	23.2	0
1¼″	24,300	35,800	44,700	26.1	0
1/2″ 30° X	23,200	34,400	41,800	26.6 x 10^6	0
3/4″	25,900	35,700	42,600	26.6	0
1″	26,200	35,400	45,900	26.2	0
1¼″	22,800	36,000	43,000	22.3	0
1/2″ 45° X	27,800	35,500	45,400	27.5 x 10^6	0
3/4″	29,400	36,400	51,500	28.4	2
1″	32,500	38,200	49,400	28.8	0
1¼″	27,800	40,900	53,100	27.6	4

The welded plates for the fatigue tests were 10 in. long. In cutting the test pieces from them ⅝ in. on either end was cut off and discarded. The remainder was then cut into 12 ½ in. square pieces, from which the test specimens were machined. Since the testing machine will take only one size specimen, ½ in. plates only were used. Single V and double V

joints were tested, and the scarf angles were 0 deg., 30 deg and 45 deg. A total of 60 test pieces was used in these tests, with the results given in Table VI. The curves from which these limits were ascertained are given in Fig. 11.

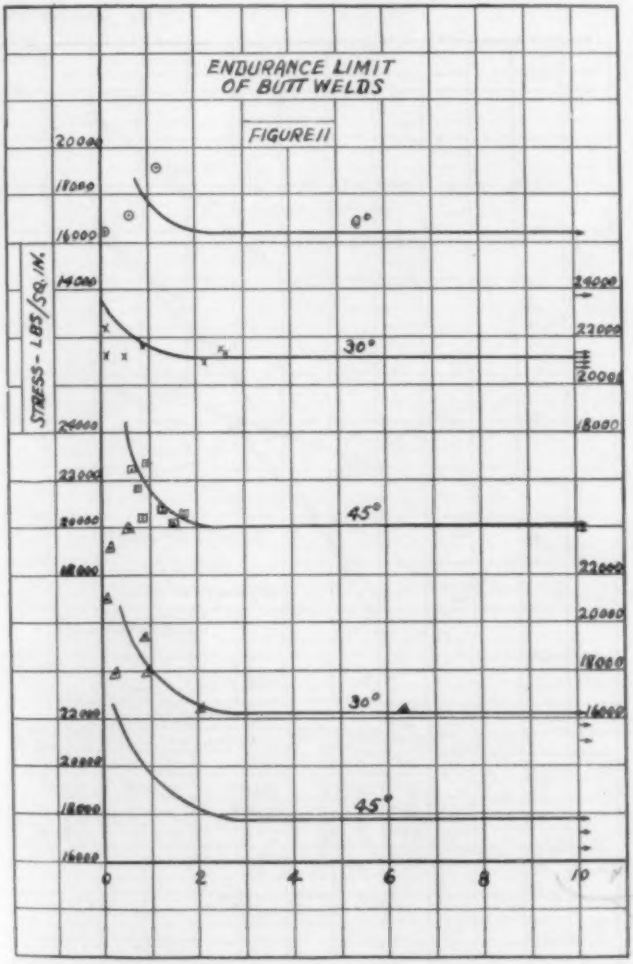


Fig. 11.

10⁶ cycles

10,000,000 cycles

Table VI

Fatigue Strength of Welded Joints

Type of Weld	Endurance Limit, Lb./Sq. In.
0°	16,000
30° V	21,000
45° V	20,100
30° X (double Vee)	16,200
45° X (double Vee)	17,800

V. *Discussion*

In determining the effect on the strength of welded joints of the three variables studied in this investigation each will be taken up separately.

The effect of varying the scarf angle will be noted first. This may best be seen by referring to Fig. 12. This shows a definite increase in

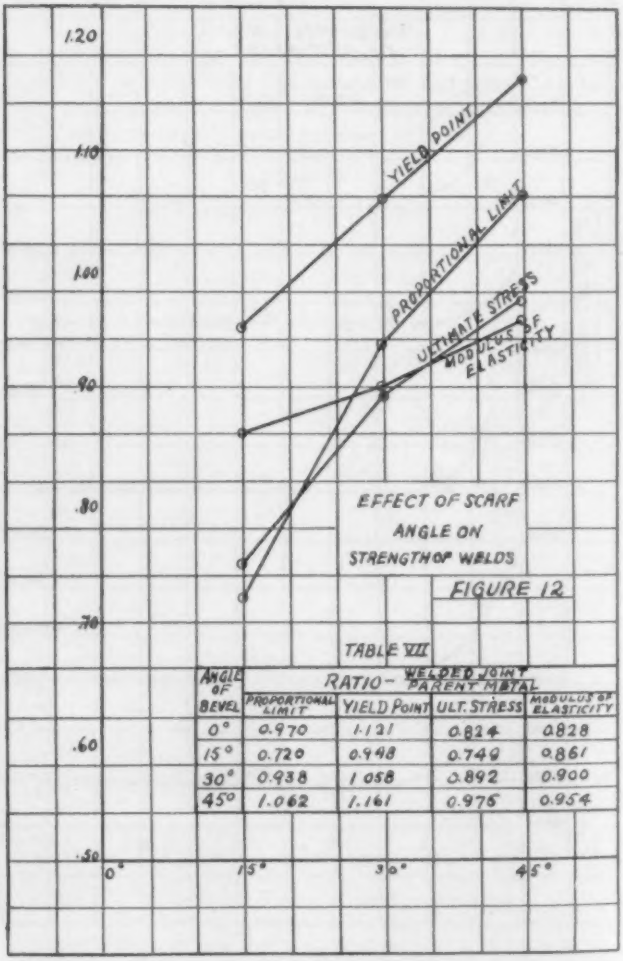


TABLE VII

Angle of Bevel	Ratio – Welded Joint / Parent Metal			
	Proportional Limit	Yield Point	Ult. Stress	Modulus of Elasticity
0°	0.970	1.121	0.824	0.828
15°	0.720	0.948	0.749	0.861
30°	0.938	1.058	0.892	0.900
45°	1.062	1.161	0.975	0.954

FIG. 12

the value of the mechanical properties with increase in the scarf angle (to 45 deg.). This was found to be so for all of the thicknesses of material tested. The scarf angle was not made greater than 45 deg. since a larger angle would have carried the investigation beyond the range of practical joints.

We find that there is an increase in efficiency (ratio of ultimate strength

of the weld to ultimate strength of the parent metal) of 14 per cent by increasing the angle from 15 deg. to 30 deg. and an increase of 9 per cent by increasing the angle from 30 deg. to 45 deg. A corresponding increase is present in the proportional limit, yield point and modulus of elasticity. However, the fatigue strength shows little difference between the 30 deg. and 45 deg. bevels.

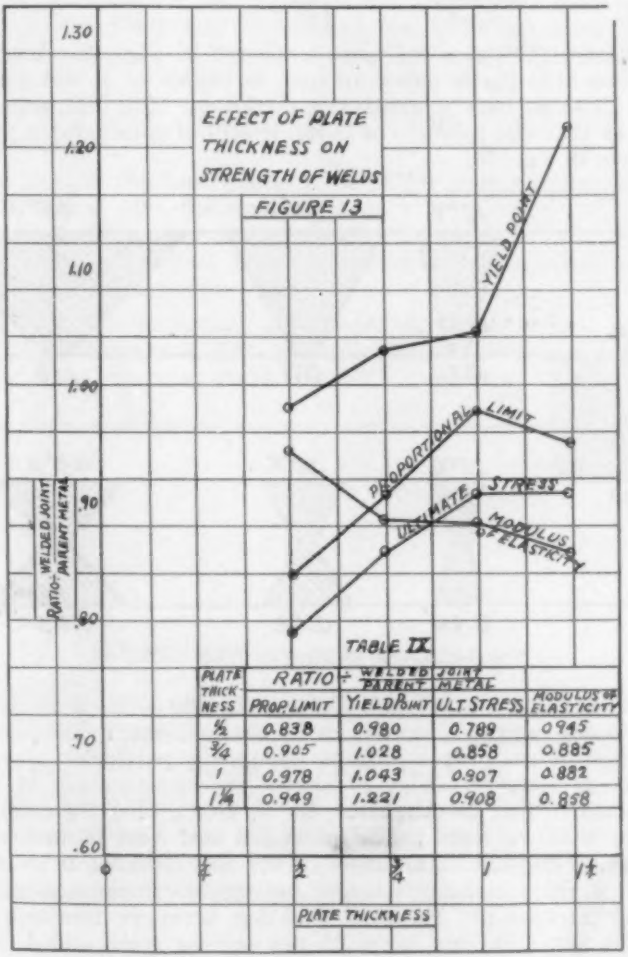


TABLE IX

PLATE THICKNESS	RATIO – WELDED JOINT / PARENT METAL: PROP. LIMIT	YIELD POINT	ULT. STRESS	MODULUS OF ELASTICITY
½	0.838	0.980	0.789	0.945
¾	0.905	1.028	0.858	0.885
1	0.978	1.043	0.907	0.882
1¼	0.949	1.221	0.908	0.858

FIG. 13

The effect of the type of bevel is readily seen from Table VIII. The single V is seen to be definitely stronger than the double V, the difference in ultimate strength amounting to an average of 7 per cent greater strength for the single V, with corresponding differences for the other tensile properties. This difference is even greater in the fatigue strength,

the single V showing an increase of 21 per cent in the endurance limit over the double V.

Table VIII

Effect of Type of Bevel on Strength of Welds

Type of Bevel	Ratio—Welded Joint / Parent Metal			
	Prop. Limit	Yield Point	Ult. Stress	Modulus B
Sirgle V	0.916	1.097	0.907	0.927
Double V	0.898	1.021	0.836	0.889

The effect of thickness of plate is shown in Fig. 13. We note from these curves that plates below an inch in thickness do not give as good joints as those an inch or greater in thickness. The difference while not as great as that due to angle of bevel, is still of considerable importance, as is shown in Fig. 13.

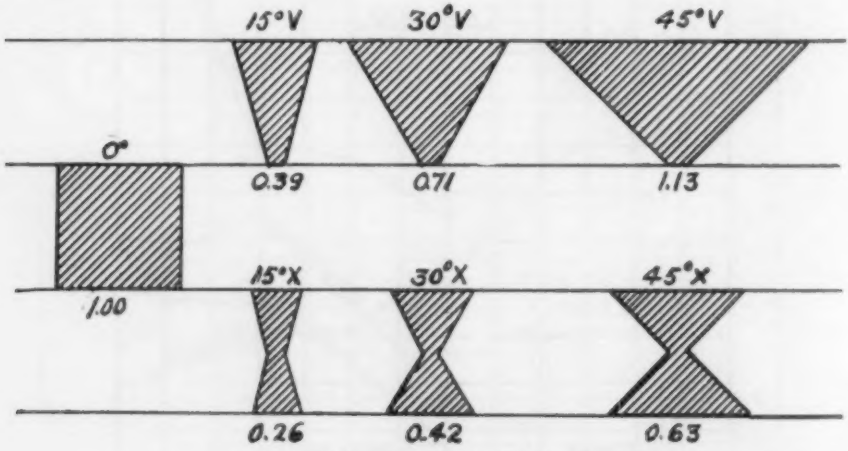


Fig. 14. Cross Section of Welds Studied

From a study of Fig. 12 and Tables VII and VIII, it is readily seen that the 45 deg. single V joint is easily the best among the joints tested. The question of the proper joint to use in any particular case is not so easily solved, however. Fig. 14 shows the cross-section of the seven welds studied in this investigation, the figures giving the cross-sectional area of the weld, referred to the unbeveled butt weld as unit, and for an inch thickness of plate. The effect of the free distance is to change the area ratio slightly, making it larger for smaller thicknesses and smaller for greater thicknesses. However, a 15 deg. bevel requires approximately 35 per cent and a 30 deg. bevel 65 per cent as much added metal as a 45 deg. bevel, and a double V joint about 60 per cent as much as a single V.

The choice of joint is then influenced by the economic factors depending on the use to which each particular weld is to be put. For the thicknesses within the scope of this paper, the 45 deg. single V joint is recommended for use in cases where strength and reliability are paramount. Where unit stresses are low, and the weld is only used to join two plates,

a poorer joint would be adequate, such as, for example, a 30 deg. single V or 45 deg. double V. The 15 deg. bevel and straight are of little practical use, the 15 deg. joint being weak and unreliable, and the straight butt joint requiring too much weld metal for the strength developed. In addition, both of these joints are likely to be poor unless a very good welder makes the joint.

VI. *Conclusion*

In conclusion, we find that the results of the preliminary tests showed that a departure from standard test pieces has to be made for welded joints, the specimen shown in Fig. 6 being selected as most suitable for the purpose.

From all the tests made, the following conclusions were reached about the variables studied.

(1) 45 deg. is the best angle of bevel for a joint, the strength decreasing with the angle.
(2) A single V joint is stronger than a double V.
(3) Strength of welded joints increases up to at least a 1 in. thickness of plate.

A 45 deg. single V joint is thus determined as being the best joint as far as strength is concerned, but economic factors dictate the use of other types for cases where strength is not the main factor.

INSTRUCTION MANUALS

Instruction manuals are available for arc, gas, resistance and thermit welding. These manuals cover fundamental information relative to these several processes of welding and are designed primarily to meet the needs of the student welder and engineer. Price per copy 50c. Lots of 100—$30.00. American Welding Society, 29 West 39th Street, New York, N. Y.

Design of Joints for Welded Steel Structures*

By ANDREW VOGEL†

THE design of joints for welded steel structures is the most important problem arising in the application of welding to structural steel frames In order to design the joints, two essentially different problems must be solved; the first is an analysis of the stresses in the structure with complete calculations with respect to forces applied at the joints, and the second is the determination of the unit stresses to be used in designing the various welds on different types of joints. The calculation of stresses in structures, while essential to the design of joints, is really a separate problem, not a part of this paper, because the theory of structures was completely developed prior to the introduction of welding.

The same methods used to determine the stresses in riveted structures are used to determine the stresses in welded structures. By tests of full size trusses at Trenton, N. J., Dec. 16, 1927, it was definitely established that the same methods of calculation were applicable. The design of joints is therefore reduced to the analysis of the stresses in the various forms of joints, occasioned by the application of welds in different positions, and by the arrangement of members in the positions best suited for welding. This study has been carried out with respect to typical forms of joints with the result that there has been evolved a number of joint types thoroughly suited to welding. In this paper only those joints which have been successfully used will be given in detail in order that the paper may be used for reference purposes and also as a basis upon which to develop additional standards.

Before preparing any designs, it was necessary to determine the values of unit stresses to be used in the various types of welds. There are now available the results of 173 tests of metal arc welds, indicating the uniformity of strength and reliability of the welds. From Fig. No. 1 it will be observed that all ¼-in. welds failed at a stress of 10,500 lb. per linear inch or more; all 5/16-in. welds failed at a stress of 11,500 lb. per linear inch or more, and all ⅜-in welds failed at a stress of 12,500 lb. per linear inch or more. From these tests it was concluded that the proper design value to use was 2000 lb. per linear inch for ¼-in. welds; 2500 lb. per linear inch for 5/16-in. welds and 3000 lb. per linear inch for ⅜-in. welds. These values result in a factor of safety of four or more in all cases. Observation of the design of test specimens will indicate that the various types of welds which will be encountered in design are represented, and also that the bars of the test specimens were sufficiently large so that the stresses in the bars were well within the elastic limit at the time the welds

*To be presented before the Annual Meeting of the American Welding Society, April 25, 1929.

†General Electric Company, Schenectady, N. Y.

failed. In other words, the welds and not the bars were tested. The results of the tests are best determined by study of the information summarized in Fig. No. 1.

Welded steel structures include several distinct parts, such as trusses, columns and beams and girders. Trusses require detailed

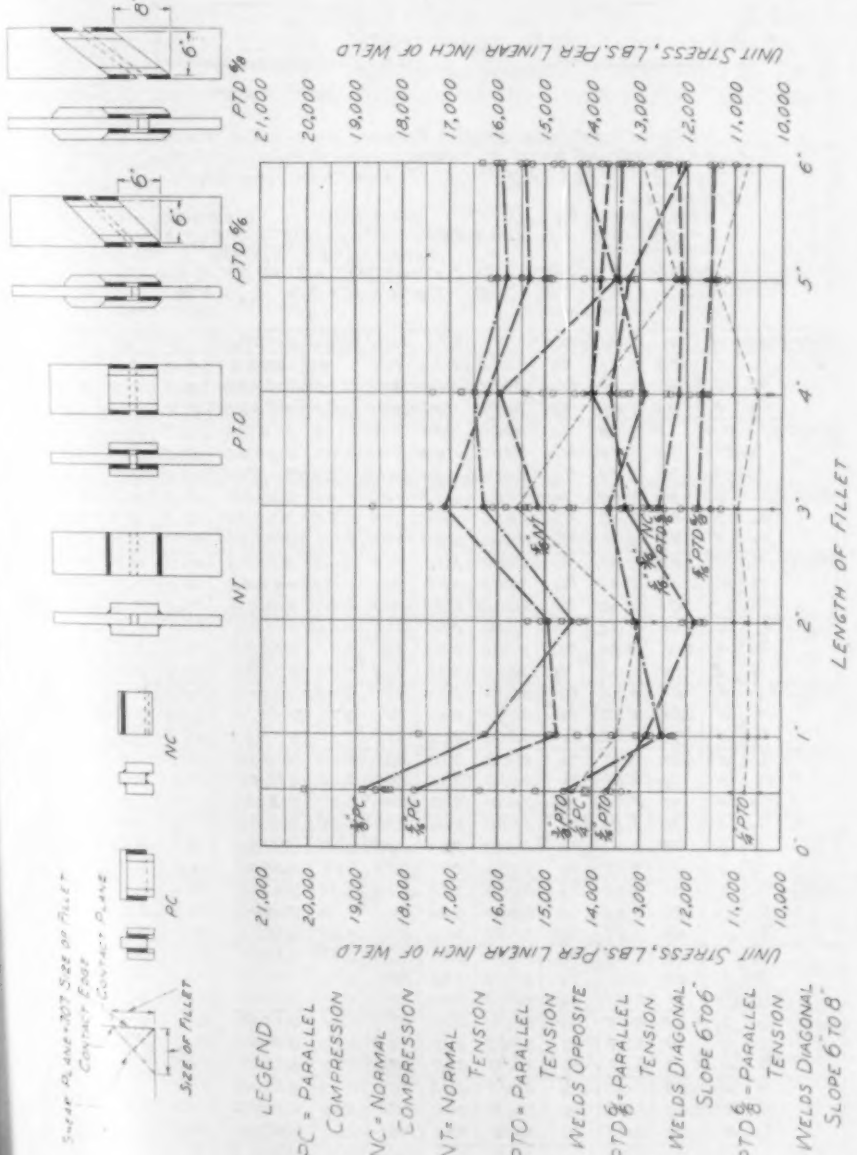
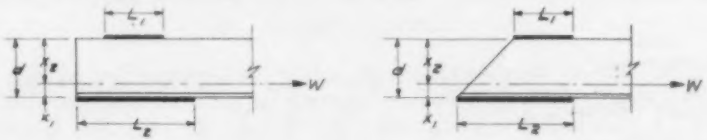


FIG. 1. TESTS OF 173 SPECIMENS OF METAL ARC WELDS

analysis to determine the stresses in the various members produced by the applied loads. Columns require tabulation of all of the loads

STANDARD SINGLE ANGLE CONNECTIONS



W=Load on Angle. S=Unit Stress per lin in Weld.
L=Length of Weld in inches $W/S=L$ $L=L_1+L_2$
$L_1 d=L x_1$ $L_1=L x_1/d$ $L_2 d=L x_2$ $L_2=L x_2/d$

Examples:
Strut 4x4x3/8 L x 7'-0" W=31600 S=3000
L=W/S=10.5" L_1=10.5x.285=3.0" L_2=10.5"x.715=7.5"
Detail L_1=3" L_2=7½"
Tension 2½ x 2½ x ¼ L x 18000$^{\#/in}$ = 21420$^{\#}$. From
Table L_1=3.1" L_2=7.6" Detail L_1=3¼" L_2=7¾"

Size Angle	d	x_1	x_2	Weld	S	x_1/d	x_2/d	Area	Ax18000	L	L_1	L_2
2x2x¼	2	.59	1.41	¼	2000	.295	.705	.94	16920	8.5	2.5	6.0
5/16	2	.61	1.39	5/16	2500	.305	.695	1.15	20700	8.3	2.5	5.8
3/8	2	.64	1.36	3/8	3000	.320	.680	1.36	24480	8.2	2.6	5.6
2½x2½x¼	2½	.72	1.78	¼	2000	.288	.712	1.19	21420	10.7	3.1	7.6
5/16	2½	.74	1.76	5/16	2500	.296	.704	1.47	26460	10.6	3.1	7.5
3/8	2½	.76	1.74	3/8	3000	.304	.696	1.73	31140	10.4	3.2	7.2
3x3x¼	3	.84	2.16	¼	2000	.280	.720	1.44	25920	13.0	3.6	9.4
5/16	3	.87	2.13	5/16	2500	.290	.710	1.78	32040	12.8	3.7	9.1
3/8	3	.89	2.11	3/8	3000	.297	.703	2.11	37980	12.7	3.8	8.9
3½x3½x5/16	3½	.99	2.51	5/16	2500	.283	.717	2.09	37620	15.0	4.2	10.8
3/8	3½	1.01	2.49	3/8	3000	.289	.711	2.48	44640	14.9	4.3	10.6
7/16	3½	1.04	2.46	3/8	3000	.297	.703	2.87	51660	17.2	5.1	12.1
4x4x 3/8	4	1.14	2.86	3/8	3000	.285	.715	2.86	51480	17.2	4.9	12.3
7/16	4	1.16	2.84	3/8	3000	.290	.710	3.31	59580	19.9	5.8	14.1
½	4	1.18	2.82	3/8	3000	.295	.705	3.75	67500	22.5	6.7	15.9
6x6x 3/8	6	1.64	4.36	3/8	3000	.273	.727	4.36	78480	26.2	7.1	19.1
½	6	1.68	4.32	3/8	3000	.280	.720	5.75	103500	34.5	9.7	24.8
5/8	6	1.73	4.27	3/8	3000	.288	.711	7.11	127980	42.7	12.3	30.4
4x3x 3/8	4	1.28	2.72	3/8	3000	.320	.680	2.48	44640	14.9	4.8	10.1
3/8	3	.78	2.22	3/8	3000	.260	.740	2.48	44640	14.9	3.9	11.0
7/16	4	1.30	2.70	3/8	3000	.325	.675	2.87	51660	17.2	5.6	11.6
7/16	3	.80	2.20	3/8	3000	.267	.733	2.87	51660	17.2	4.6	12.6
½	4	1.33	2.67	3/8	3000	.332	.668	3.25	58500	19.5	6.5	13.0
½	3	.83	2.17	3/8	3000	.277	.723	3.25	58500	19.5	5.4	14.1
5x3½x 3/8	5	1.61	3.39	3/8	3000	.322	.678	3.05	54900	18.3	5.9	12.4
3/8	3½	.86	2.64	3/8	3000	.246	.754	3.05	54900	18.3	4.5	13.8
7/16	5	1.63	3.37	3/8	3000	.326	.674	3.53	63540	21.2	6.9	14.3
7/16	3½	.88	2.62	3/8	3000	.251	.749	3.53	63540	21.2	5.3	15.9
½	5	1.66	3.34	3/8	3000	.332	.668	4.00	72000	24.0	8.0	16.0
½	3½	.91	2.59	3/8	3000	.260	.740	4.00	72000	24.0	6.2	17.8
6x4x 3/8	6	1.94	4.06	3/8	3000	.323	.677	3.61	64980	21.7	7.0	14.7
3/8	4	.94	3.06	3/8	3000	.235	.765	3.61	64980	21.7	5.1	16.6
½	6	1.99	4.01	3/8	3000	.332	.668	4.75	85500	28.5	9.5	19.0
½	4	.99	3.01	3/8	3000	.248	.753	4.75	85500	28.5	7.1	21.4
5/8	6	2.03	3.97	3/8	3000	.338	.662	5.86	105480	35.2	11.9	23.3
5/8	4	1.03	2.97	3/8	3000	.258	.743	5.86	105480	35.2	9.1	26.1

FIG. 2

tributary to or applied to the columns. Beams and girders are designed for the loads to which they are subjected, whether uniform or concentrated; but, also, in preparing the calculations, the reactions at the ends of the beams and girders are determined in order to design the connections from beams to girders or girders to columns. Occasionally structural members and connections must also be designed for combined bending and direct stress. The design problems, therefore, are preliminary to the determination of the forces acting at the various joints. The design data thus collected is also used to determine the arrangement of the members at the connections. This paper

STANDARD SINGLE CHANNEL TENSION CONNECTIONS

W=Load on Channel. S=Unit Stress per 1 in. in Weld.
L=Length of Weld in inches. $W/S=L$ $L_1=L_2=L/2$

Examples:
3"Channel 4.1# W=21400 S=3000 L=W/S=7.1" $L_1=L_2=3.6$"
Detail $L_1=L_2=3\frac{3}{4}$"

5"Channel 9.0# W=47300 S=3000 L=W/S=15.8" $L_1=L_2=7.9$"
Detail $L_1=L_2=8$"

Size Channel	Weight	Area	Area x 18000	Weld	S	L	$L_1=L_2$
3	4.1	1.19	21400	3/8	3000	7.1	3.6
	5.0	1.46	26300	3/8	3000	8.8	4.4
	6.0	1.75	31500	3/8	3000	10.5	5.3
4	5.4	1.56	28100	3/8	3000	9.4	4.7
	6.25	1.82	32800	3/8	3000	10.9	5.5
	7.25	2.12	38200	3/8	3000	12.7	6.4
5	6.7	1.95	35100	3/8	3000	11.7	5.9
	9.0	2.63	47300	3/8	3000	15.8	7.9
	11.5	3.36	60500	3/8	3000	20.2	10.1
6	8.2	2.39	43000	3/8	3000	14.3	7.2
	10.5	3.07	55300	3/8	3000	18.4	9.2
	13.0	3.81	68600	3/8	3000	22.8	11.4
	15.5	4.54	81700	3/8	3000	27.2	13.6
7	9.8	2.85	51300	3/8	3000	17.1	8.6
	12.25	3.58	64400	3/8	3000	21.5	10.8
	14.75	4.32	77800	3/8	3000	25.9	13.0
	17.25	5.05	90900	3/8	3000	30.3	15.2
	19.75	5.79	104200	3/8	3000	34.7	17.4
8	11.5	3.36	60500	3/8	3000	20.2	10.1
	13.75	4.02	72400	3/8	3000	24.1	12.1
	16.25	4.76	85700	3/8	3000	28.6	14.3
	18.75	5.49	98800	3/8	3000	32.9	16.5
	21.25	6.23	112100	3/8	3000	37.4	18.7

FIG. 3

will analyze and illustrate the problems involved for various connections for individual members and also the assembly of individual members into trusses and structures.

Trusses require a greater variety of joints than any other element in a structure, and for this reason a greater proportionate study has been given to the joints in trusses. Analysis of the joints in trusses reminds one that the fundamental principles are the same in all trusses and therefore these principles should be restated. Truss lines should intersect at a point and loads applied to the trusses should be applied at these points. The center of gravity of the truss members

STANDARD SINGLE TEE TENSION CONNECTIONS

W=Load on Tee. S=Unit Stress per lin. in. Weld.
L=Length of Weld in inches. W/S=L $L_1=L_2=L/2$

Examples:
2x2 Tee 4.3# W=22700 S=2500 L=W/S=9.1" $L_1=L_2=4.6$"
Detail $L_1=L_2=4\frac{3}{4}$"

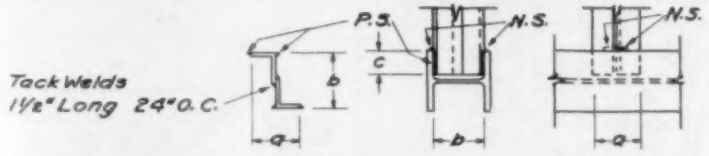
4x3 Tee 9.2# W=48200 S=3000 L=W/S=16.1" $L_1=L_2=8.1$"
Detail $L_1=L_2=8\frac{1}{4}$"

Size Tee	Weight	Area	Area x 18000	Weld	S	L	$L_1=L_2$
2x2	3.56	1.05	18900	1/4	2000	9.5	4.8
2x2	4.3	1.26	22700	5/16	2500	9.1	4.6
2¼x2¼	4.1	1.19	21400	1/4	2000	10.7	5.4
2¼x2¼	4.9	1.43	25700	5/16	2500	10.3	5.2
2½x2½	5.5	1.60	28800	5/16	2500	11.5	5.8
2½x2½	6.4	1.87	33700	3/8	3000	11.2	5.6
3x3	6.7	1.95	35100	5/16	2500	14.0	7.0
3x3	7.8	2.27	40900	3/8	3000	13.6	6.8
4x4	10.5	3.09	55600	3/8	3000	18.5	9.3
4x4	13.5	3.97	71500	3/8	3000	23.8	11.9
6½x6½	19.8	5.80	104400	3/8	3000	34.8	17.4
2½x3	6.1	1.77	31900	5/16	2500	12.8	6.4
3x2½	6.1	1.77	31900	5/16	2500	12.8	6.4
4x2½	7.2	2.12	38200	5/16	2500	15.3	7.7
4x2½	8.5	2.48	44600	3/8	3000	14.9	7.5
4x3	7.8	2.29	41200	5/16	2500	16.5	8.3
4x3	9.2	2.68	48200	3/8	3000	16.1	8.1
4x4½	11.2	3.29	59200	3/8	3000	19.7	9.9
4x4½	14.4	4.23	76100	3/8	3000	25.4	12.7
4x5	11.9	3.49	62800	3/8	3000	20.9	10.5
4x5	15.3	4.50	81000	3/8	3000	27.0	13.5
5x3	11.5	3.37	60700	3/8	3000	20.2	10.1

FIG. 4

and the center of gravity of the welds applied at the joints should coincide with the truss lines. If these principles are observed no secondary stresses are developed as a result of eccentric connections, because the center of gravity of the member is not located on the truss lines. These principles naturally tend to encourage the use of symmetrical sections for truss members but, as it is not always economical nor practical to use symmetrical sections, it is necessary to develop methods for using non-symmetrical sections. To accomplish this purpose joint details have been developed for non-symmetrical members frequently used such as angles. Angles would require the use of eccentric joints, but for the fact that it is possible to

TYPICAL TWO ANGLE Z STRUT CONNECTIONS



W=Load on Strut. S=Unit Stress per lin. in Weld. L=Length of Weld in inches. F=Allowable Unit Stress on Strut=16000-70x l/r. L=W/S. N.S.=Normal Shear Weld. P.S.=Parallel Shear Weld. c=Length Available for P.S.

Examples:

2-Ls 4x3x5/16 a=6" b=7.2" 5/16" Weld. S=2500 r=1.2
l=10'=120" F=16000-70x120/1.2 = 9000. Area=2x2.09=4.18 W=4.18x9000=37620 L=37620÷2500=15.05"
c=3⅜" L-4x3⅜=15.05-13.5=1.55 1.55/2=.78 Detail N.S.=1"

2-Ls 4x4x⅜ a=8" b=7.2" ⅜" Weld. S=3000 r=1.69
l=10'=120" F=16000-70x120/1.69=11030. Area=2x2.86=5.72 W=5.72x11030=63200 L=63200÷3000=21.07"
c=3⅜" L-4x3⅜=21.07-13.5=7.57 7.57/2=3.79 Detail N.S.=4"

FIG. 5

proportion the welding used for connecting angles to other members in such manner that the center of gravity of the amount of welding used coincides with the center of gravity of the member and the truss lines. The design of joints for trusses, therefore, involves the use of symmetrical connections occasioned by the use of tees and channels and the design of non-symmetrical connections occasioned by the use of angles. In this paper tables and examples are given of such connections used in the design of welded trusses.

The tables and examples illustrating the use of members used in welded steel trusses are shown in Figs. 2 to 7 inclusive. Fig. No. 2 illustrates single angle connections. The dimensions and properties of the section of an angle determine the amount of welding to be

placed on either edge of the angle. Moments about the center of gravity of the angle produced by the amount of welding used are made equal so that no unbalanced moment will be transmitted to the member or unequal stresses applied to the welds. The derivation of the for-

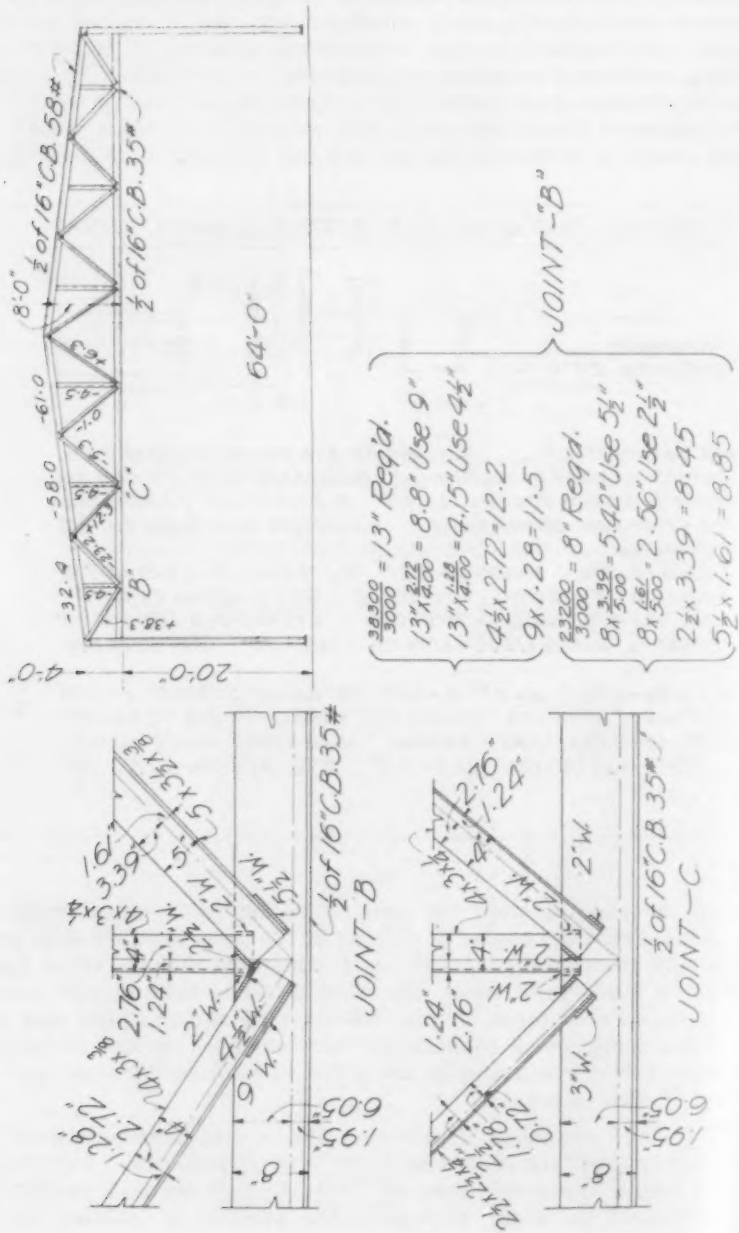


Fig. 6. Welded Truss Using Angles for Web Members and One-Half Carnegie Beams for Chords

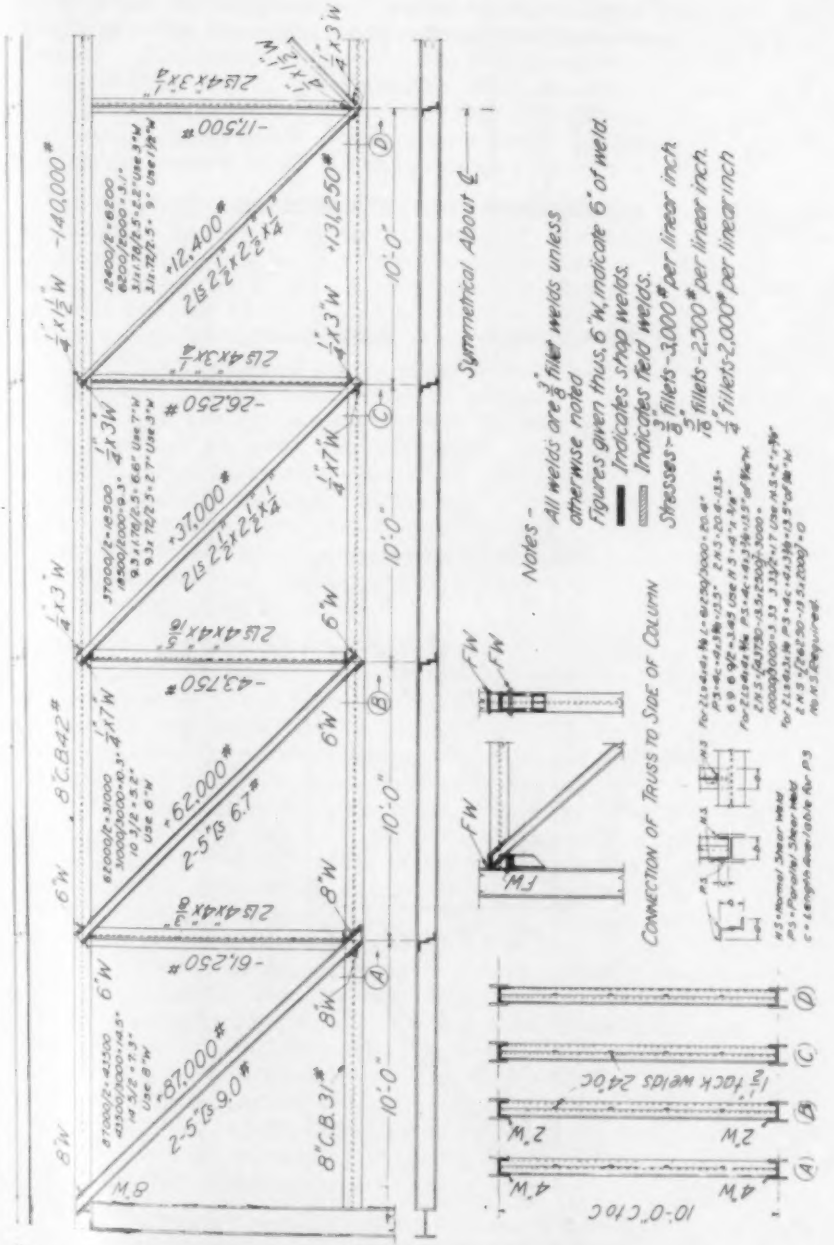

Symmetrical About ℄
Notes -
All welds are 5/16" fillet welds unless otherwise noted
Figures given thus, 6"W, indicate 6" of weld.
Indicates shop welds.
Indicates field welds.
Stresses - 5/16" fillets - 3,000# per linear inch
1/2" fillets - 2,500# per linear inch.
5/16" fillets - 2,000# per linear inch
CONNECTION OF TRUSS TO SIDE OF COLUMN
10'-0" C to C
1/2" TACK WELDS 24" OC

FIG. 7. WELDED TRUSS USING ANGLES, CHANNELS AND Z STRUTS FOR WEB MEMBERS AND CARNEGIE BEAMS FOR CHORDS

mula and examples given in Fig. No. 2 illustrates this important problem. Standard single channel tension connections are given in Fig No. 3 and standard single tee tension connections are given in Fig. No.

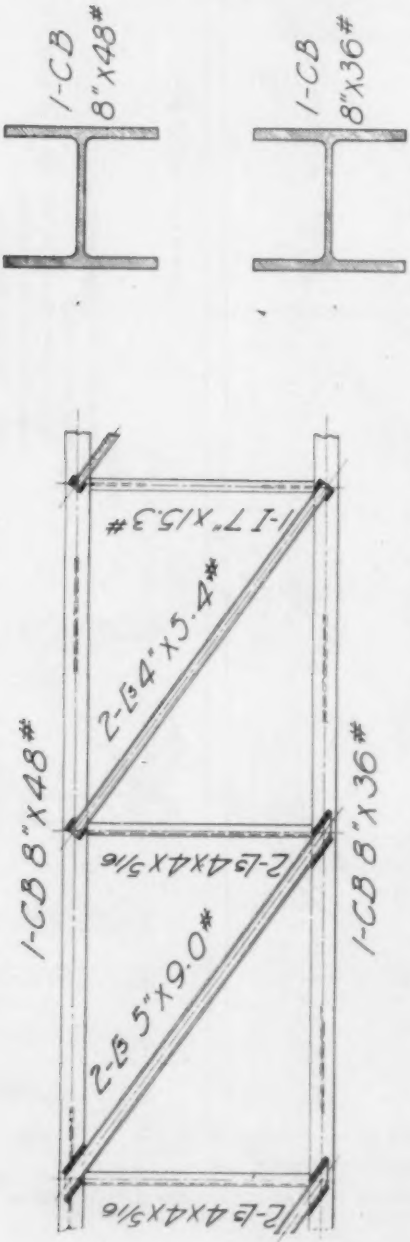


FIG. 8. WELDED TRUSS USING CHANNELS AND ANGLES FOR WEB MEMBERS AND CARNEGIE BEAMS FOR CHORDS

4 but, as both these members are symmetrical about their center lines, the number of linear inches of weld is made equal on both edges of the members. Fig. No. 5 illustrates connections used for typical two angle Z struts. The examples given in Fig. No. 5, coupled with the examples given in Fig. No. 7, illustrate the methods used to determine the amount and position of the welds. Fig. No. 6 illustrates typical connections of single angle members to a chord composed of one-half of a Carnegie beam with all the calculations prepared in detail.

The development of welded trusses encouraged the use of new types of members and also the use of members heretofore not extensively used in trusses. Analysis of chord sections indicated that, if gusset plates were to be eliminated, it would be necessary to have wide flat surfaces parallel to the plane of the truss on which the web members could be welded. Further study indicated that Carnegie beams and large tees, obtained by splitting large beams with the aid of the torch, would provide suitable chord sections and the necessary surface to which the web members could be welded. The Carnegie beam section, placed with its web horizontal, as illustrated in Fig. No. 8, provided a chord exceedingly stiff or strong in the horizontal plane, thus considerably reducing the amount of horizontal bracing required for trusses of long span. Beams split in two, as illustrated in Fig. No. 9, provided tees of equal capacity to the pairs of angles formerly used in riveted design, and also provided the wide flat surfaces to which web members could be welded.

Even the web members of the trusses were modified in design to suit welded joints. Channels are extensively used for tension members as it is possible to use ⅜-in. welds on both web edges of the channels, thus developing welds with a capacity of 3000 lb. per linear inch of weld and resulting in short connections. In the design of joints when channels are used, the amount of welding required is frequently so long that it is not possible to place the welds directly opposite each other. In this case, however, welds can be placed on both edges of the channels across the full width of the chord member if necessary, and tests indicate that welds placed in such positions are practically equal in strength to those placed directly opposite each other. The same unit stresses, therefore, are used for such welds. Tees are also suitable as web members and their connections are designed similar to the connections for channels. Angles are used with preference given to angles with metal ⅜ in. thick so that ⅜-in. welds can be used. Where it is economical to use angles with metal ¼ in. or 5/16 in. thick, ¼-in. or 5/16-in. welds are used with the welds designed on a basis of 2000 lb. per linear inch for ¼-in. welds and 2500 lb. per linear inch for 5/16-in. welds. The design of joints for compression or tension web members consisting of single or paired angles, is given in detail in Fig. No. 2 in this paper.

When Carnegie beams are used for chord sections, a new form of strut is used known as the Z strut. The Z strut, illustrated in Fig. No. 5, consists of two angles so arranged that adjacent legs are welded together to convert the two angles into a single member. The outer legs

of the angles are welded to the inner surfaces of the flanges of the Carnegie beams. Unfortunately the connection of a Z strut to the inner surface of the Carnegie beam chord section is sometimes compli-

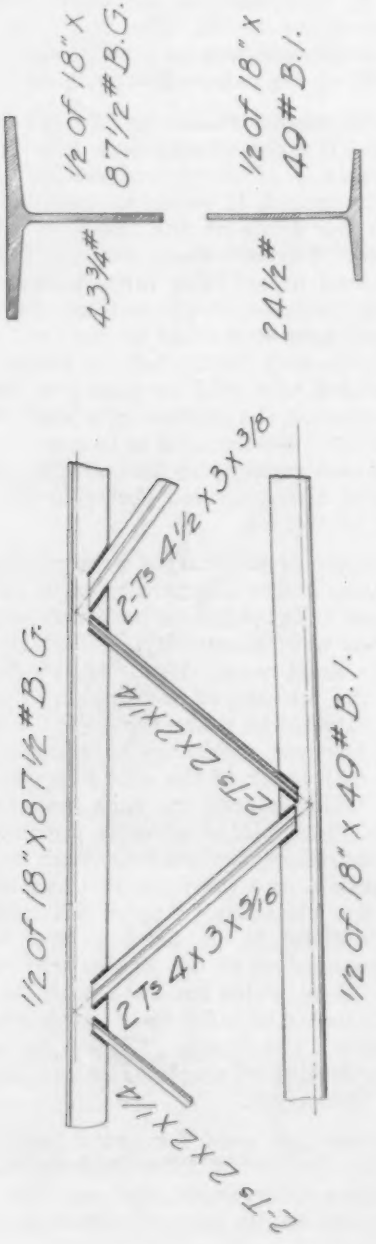


FIG. 2. WELDED TRUSS USING TEES FOR WEB MEMBERS AND ONE-HALF BETHLEHEM GIRDERS OR I BEAMS FOR CHORDS

cated by the fact that the plane surface of the Carnegie beam does not extend all the way to the web because of the fillet so necessary between the web and the flange. As a rule, however, sufficient welding can be applied to the four edges of the Z strut in contact with the inner surfaces of the Carnegie beam, but if this amount of welding is insufficient, additional welding can be applied between Z struts and the edges of the chords. It is also possible to place a plate between the end of the Z strut and the web of the chord, but this additional provision would only be required in the case of exceptionally heavy trusses.

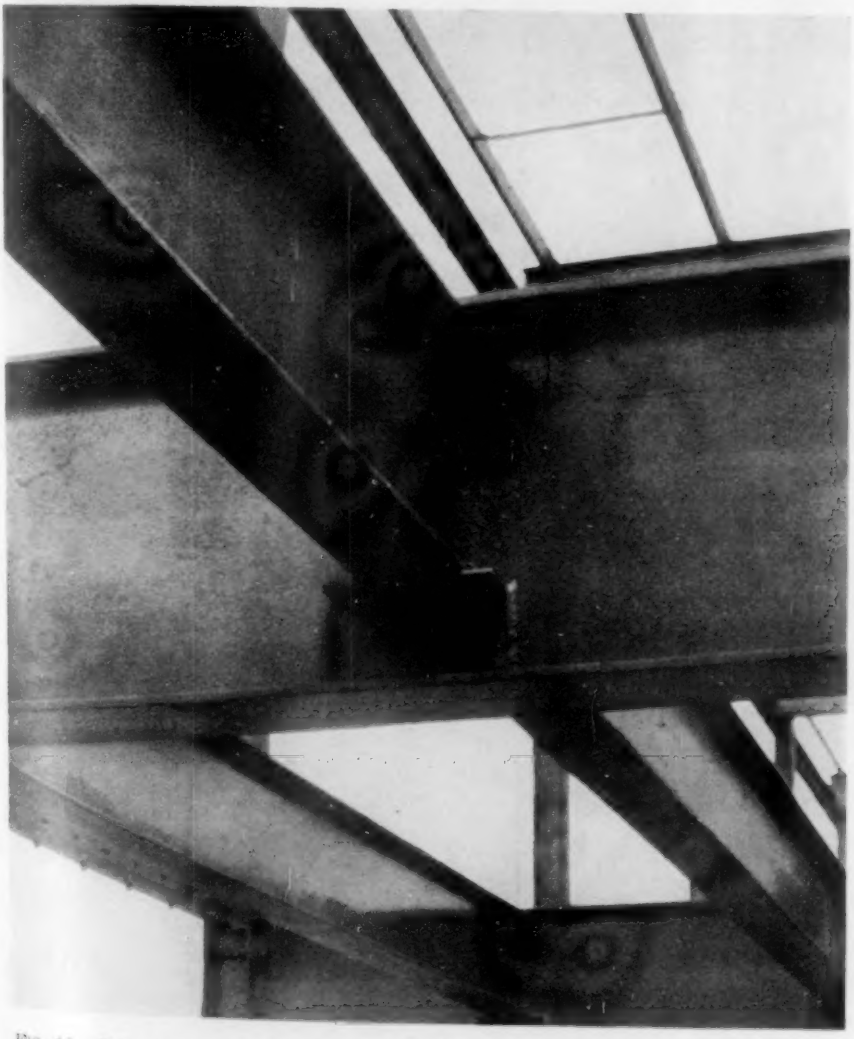


FIG. 10. DETAIL OF CLIP ANGLE SHOWING WELDING OF ANGLE TO GIRDER AND HOOK BOLT HOLDING BEAM TO CLIP ANGLE

The connections of beams to girders and of girders to columns involve two types of connections known as brackets and web connections. Present experience indicates that bracket connections are cheaper than web connections because the bracket connections can be fabricated in the shop and the brackets can contain all the holes required for fastening the beams to the girders or the girders to the columns. At this point it is well to mention that a fundamental principle in the design of welded connections is that all punching should

FIG. 11. DETAIL OF COLUMN ANCHORAGE SHOWING EQUAL LEG ANGLE WELDED TO STEEL COLUMN

be performed in the clip angles or bracket details, and that punching should be avoided in all heavy members. If brackets are well designed and attached to the girders or columns in the shop, field welding is minimized. The design of welded brackets has not reached the point where it is possible to call any design typical or standard. This detail usually consists of a clip angle, as illustrated in Fig. No. 10, with the horizontal leg of the angle of sufficient width (usually 4 in.) to permit punching 13/16-in. holes for ¾-in. hook bolts in order to support and to hold the girder or beam securely in position. The vertical leg of the angle should be of sufficient width to provide on each end of the angle welding edges of sufficient size to support the load to be transmitted from beam to girder or from girder to column. An example might be a beam with a reaction of 35,000 lb. This weight divided by 3000 lb. per linear inch for a ⅜-in. weld, would require 11 2/3 or 12 lin. in. of weld. If the weld should be applied to the two ends of the clip angle, the leg of the clip angle must be 6 in. wide to permit the proper amount of welding at each end. If a heavier reaction must be provided for, a similar procedure is required except that it is frequently necessary to place the angles in a vertical position and then to place a plate on top of the angles to provide the seat for the beams or girders.

If web connections are used for beams and girders, angles should be welded to the girders or columns with sufficient welding to care for the dead load of the member. After the member is erected in position the proper number of linear inches of weld should be applied to each side of the web of the girder in order to connect the web to the column. The particular disadvantage of directly connecting the web of a beam to a girder or the web of a girder to a column is that it becomes necessary to cut the beam or girder to exact length, thus increasing the cost of shop fabrication. It is, therefore, recommended that, wherever possible, shop welded brackets (either clip angles or heavier built-up brackets) be used in order to eliminate the cost of cutting beams to exact length and to minimize the amount of field welding. No details of brackets are shown in this paper because such details are not yet developed in such form as to justify suggesting them for use as standards

The connection of columns to base plates or foundations is illustrated in Fig. No. 11, which shows an equal leg angle welded to a steel column at its foot. The use of an angle or a bent plate in "U" form has been quite general. The method of design is simple. The stress in the anchor bolt is determined and divided by 3000 lb. per linear inch in order to obtain the number of linear inches of welding required. This result is then divded by two to obtain length of angle or "U" plate, as two lines of welding are applied to the edges of the equal leg angle or "U" shaped plates. If there are horizontal forces applied to the column, the column can be field welded to the base plate and the base plate encased in concrete properly secured to the foundation by reinforcing steel, all as indicated in the illustration.

The design of joints for welded steel structures is in process of de-

velopment. The designs illustrated in this paper are some of those which have been developed up to the present time. There is opportunity for much further study and improvement, particularly with reference to brackets used for supporting beams and girders and also used for wind bracing. There are also many other forms of joints requiring considerable study, many tests and additional development in shop and field. As new joints and connections are developed, photographs, drawings and calculations should be published in order to advance the art. The development of welded steel structures now depends largely upon the development of the details of connections and joints.

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Oxy-Acetylene Cutting Structural Steel. S. W. Miller. The Welding Engineer (Feb., 1929), Vol. 14, No. 2, pp. 45-51. Cuts in important places should be made as smooth as possible. No detrimental effect on steel is found. Sheared surfaces more subject to cracking than torch-cut surfaces.

Oxy-Acetylene Tips. (Feb., 1929), Vol. 7, No. 7. Twenty Below! Economies Effected by Cutting Risers Hot. Pipe Utilized for Roof Trusses. Oil-tight Seams for Doughnut Kettles. He Made the Final Cuts Alone. For the

Best Oxy-Acetylene Welds in Steel. The Oxy-Acetylene Process as Applied to the Cutting of Structural Steel. An Oxwelded Stand for Airplane Work. An Up-to-Date Winter Repair. The Contract Welder Does a Special Job. How to Weld Wrought Iron Pipe.

Oxy-Acetylene Welding and Cutting. Heat Treat. & Forg. (Dec., 1928), 14. 1406-13.

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Weld Test of Heavy Column Joints Shows Good Results. Engineering News-Record (March 7, 1929), Vol. 102, No. 10, pp. 385-6. Joints which will be riveted in towers of Hudson River bridge show 11,500 lb. per inch of fillet when welded.

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Welding Pipe to Serve for All Time. The Welding Engineer (Feb., 1929), Vol. 14, No. 2, pp. 623. Cathedral built to stand for unnumbered centuries includes welded piping throughout, buried in twenty feet of masonry.

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